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NOTE

This book discusses questions of the theory and practice of exposure measurements, and considers the objective method of determining photographic exposure and the principal factors affecting its value.

The book is written for qualified readers.

Criticisms and remarks should be sent to "Iskusstvo" Publishing House, Moscow, I-51, Tsvetnoy Bul'var, 25

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INTRODUCTION

The precise determination of the time and conditions of exposure is not an easy task. Its correct solution determines not only the technical quality but also certain artistic features of still and motion pictures.

The study of the principle of the theory of exposure measurement is therefore one of the most important stages in mastering the art, and is compulsory not only for the motion picture operator and professional photographer, but also for the serious amateur photographer.

In connection with the peculiarities of multi-layer films used in color photography, and the wide employment by amateur photographer of the method of time development of negatives, the requirements for exact determination of the exposure conditions have very greatly increased. The practice of visual estimation "by eye" of the most important exposure characteristics of the object photographed and of the illumination can no longer assure the quality and necessary constancy of photographic results. The efforts looking towards a development of a technique and creation of instruments encouraging the objective solution of this very important problem is therefore entirely justified.

In this connection, on the basis of the advanced experience of professional Soviet motion-picture operator art, and the accomplishments of Soviet motion-picture technology, a scientifically founded technique has been developed for determining the conditions of exposure, and photoelectric instruments have been designed to assure the attainment of objective estimates of the exposure conditions of a photograph.

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In this book we shall discuss only those fundamental theoretical principles of exposure measurement that can be understood by the qualified amateur motion picture and still photographer.

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THE PROBLEM OF THE CORRECT DETERMINATION OF THE TIME AND CONDITIONS OF EXPOSURE IN STILL AND MOTION PICTURE PHOTOGRAPHY

The Photographic Action of Light

The light rays reflected by the objects of a photograph, passing through the camera lens, form a real optical image of the objects photographed on the sensitive layer. The illumination and color of the individual elements of this image depend on the differences of brightness and of color of the objects photographed, on certain features of the optical system of the camera, and on the transparency of the air between the objects photographed and the camera.

The photochemical action of these light rays is determined by the illuminations produced on the sensitive layer by the elements of various brightness in the optical image, by their spectral characteristics, and by the exposure time.

The quantity of illumination acting on the sensitive material during exposure may be represented, with some simplification, for each individual area of the optical image, in the form of the equation

$$H = E \times t,$$

where H is the quantity of illumination on the sensitive film, expressed in lux-sec; E its illumination in lux; t the time of action on the light of the sensitive layer, expressed in seconds. The value of the illumination of the layer E and the exposure time t in this equation are directly related to the value of the exposure* H, and

* It should be remembered that the concept of exposure, i.e. the quantity of illumination, defined as the product of the illumination of the photographic layer by the time of illumination, should not be confused with the idea of length of exposure, i.e. with the time interval during which the sensitive layer is subjected to the action of light.

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their variation should affect the variation of the value of H to the same extent.

Experience has shown, however, that for certain cases of the action of light on photographic materials, this proposition proves to be not entirely true. In studies connected with stellar photography, it has been established that at very low illumination and corresponding lengthening of the exposure time, i.e. with constant total quantity of illumination, the resultant total blackening of the sensitive layer was found to be considerably reduced.

It was found that the blackening so obtained cannot be considered directly proportional to the product E x t, and that in these cases the equation H = E x t takes the form $H = E \times t^{p}$, where p is an exponent which, for most modern negative materials, under ordinary conditions of illumination, is found to be equal to 0.8–0.9, and for individual highly sensitive materials, may go as high as 0.95. For most still and motion pictures taken under ordinary exposure conditions, the influence of this correction may be neglected, but in cases where the lens is stopped down considerably, as well as in certain cases of photography at very low illumination, the value of the necessary exposure correction may be determined by experiment or calculation.

As an example, let us consider the following case.

A certain degree of blackening of the photographic layer, defined by the optical density of the negative D*, was obtained by us as a result of the exposure H = E x t. In cases where, with decreased illumination of the object photographed, or by stopping down the lens, the illumination of the layer E is reduced by a factor of 100, the lengthening of the exposure time likewise by a factor of 100, as would

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* The density of a layer with the transmission factor 0.1, i.e. one passing 1/10 of the light falling on it, is taken as the unit of optical density, or blackening. For convenience in calculation, optical density is expressed by the common logarithm of the reciprocal of the transmission factor. The value of the optical density is proportional to the quantity of metallic silver reduced, as a result of exposure and development, on unit area of the sensitive layer.

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follow from the equation $H = E \times t$, has been found to be inadequate to obtain the same density D, at constant exposure time, owing to the influence of the factor p, with the same development time. Let us assume, arbitrarily, that the value of p is 0.79 for the negative material used in taking the picture. Then, with a 100-fold reduction in illumination of the layer, i.e. at E = E/100, the necessary exposure time t_2 is found to be not 100 t, but, in accordance with what has been set forth above, must be $100\ t^{0.79}$ (sic.). The exposure time must therefore be increased by a factor of 340 instead of 100. Obviously such a correction is of most substantial practical importance.

In connection with the varying illuminations produced on the sensitive layer by the optical images of the objects photographed, the individual areas of that layer receive varying quantities of illumination for the same exposure time. Thus, if, regardless of the brightness of the photographed objects, the blackening of the sensitive layer were found in all cases to be strictly proportional to the values of illumination of the layer, then it would be relatively easy to solve the problem of correct exposure in motion and still photography.

In reality, however, this problem is found to be incomparably more complicated. Let us discuss this subject in more detail.

The Characteristic Curve

A study of the photochemical action of light has shown that the relation between the blackening of the sensitive layer and the quantity of illumination causing that blackening is subject on the whole to certain general regularities which vary substantially according to the character and type of the films and plates used.

To elucidate the features of photographic materials, these relations are customarily expressed in graphic form in the shape of the so-called characteristic curve.

In constructing this curve a coordinate system is used, and the quantity of il-

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lumination, expressed in the form of the logarithm of the value of the exposure, is plotted on the horizontal axis, and the optical density of blackening on the vertical axis.

To study the peculiarities of the negative materials used, they are subjected to the action of quantities of illumination increasing in a certain definite order.

By developing the sensitogram so obtained under standard conditions and measuring the optical density of individual fields resulting from exposure and development, we construct the characteristic curve of the material being tested (Fig.1).

Relative quantity of illumination (the exposure Corresponding to Beginning of the Linear Segment of the Characteristic Curve is Taken as Unity)

1/8 1/4 1/2 1 2 4 8 16 32 64 12 256 512 1024

Relative Quantity of Illumination

1 2 4 8 16 32 64 128 256 512 1024 2048 4096 8192

H = lux x sec.

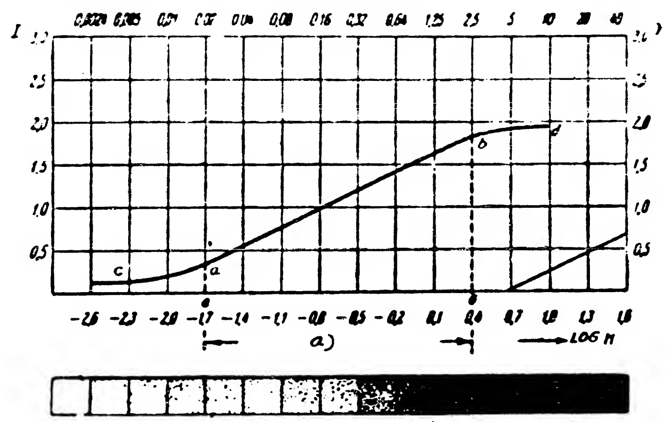

Fig.1. Sensitogram and Characteristic Curve of the Negative Material.

a) Photographic Width

As an example, let us consider the test of negative material ("Panchrom" type

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A, emulsion No.5868), the results of which are given in Table 1. As will be seen

Table 1

Ratio of Quantity of Illumination of Sensitive Layer and Density of Sensitogram

Sensitogram field No.	Quantity of illumination (exposure) for each field (in lux-sec)	Relative quantity of illumination (exposure)	Logarithm of exposure (log H)	Optical density (log of opacity)	Difference between density of adjacent sensitogram fields		Relative quantity of illumination (exposure corresponding to beginning of linear segment of characteristic curve) is taken as a unity.
1	0.0024	1	-2.6	0.12	0.00	Region of under-exposures	1/8
2	0.005	2	-2.3	0.14	0.02		1/4
3	0.01	4	-2.0	0.18	0.04		1/2
4	0.02	8	-1.7	0.36	0.18		1
5	0.04	16	-1.4	0.58	0.22		2
6	0.08	32	-1.1	0.80	0.22		4
7	0.16	64	-0.8	1.02	0.22	Region of normal exposures	8
8	0.32	128	-0.5	1.24	0.22		16
9	0.64	256	-0.2	1.46	0.22		32
10	1.25	512	0.1	1.67	0.21		64
11	2.5	1 024	0.4	1.86	0.19		128
12	5.0	2 048	0.7	1.94	0.08	Region of over-exposures	256
13	10.0	4 096	1.0	1.97	0.03		512
14	20.0	8 192	1.3	1.98	0.01		1 024

from this Table, the quantity of illumination for each successive field of the sensitogram is double that of the preceding field.

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The data of Table 1 on the differences in the optical density of adjoining fields of the sensitogram given an idea of the regularities in the increase of blackening that characterize the peculiarities of the negative material under study. At the beginning of the scale, the increase of optical density corresponding to the exposures for the second and third fields of the sensitogram is very small, and is equal to 0.02. Increasing gradually, the difference between the density of adjacent fields reaches 0.22 for the fifth and sixth field. At some segment, the increment of density remains constant, and then, from the 11th field on, begins to decline and falls to the value 0.03.

We are thus able to note the existence of three regions: in the first region, the difference between adjoining densities increases from field to field; in the second it maintains a constant value; in the third, it again begins to decrease.

Let us plot the logarithms of the exposures given in Table 1, obtained for the separate fields of our sensitogram, on the horizontal axis of a graph (Fig.1), and the optical densities corresponding to these logarithms on the vertical axis. These quantities will obviously be the coordinates of the points to be plotted on the graph. By connecting these with a smooth curve, we obtain the characteristic curve of the negative material. On considering this curve, it will be seen that it can likewise be divided into three regions, passing smoothly into each other. In the central and main part, the characteristic curve coincides with a straight line. Within the limits of this section the increase in the density of blackening is directly proportional to the logarithm of the exposure, and equal increments of exposure correspond to equal increments of optical density.

Regions of Normal Exposure, Underexposure and Overexposure

The section A-B on Fig.1 is termed the region of normal exposure, or region of proportional reproduction of the brightness of the photographed object; this is the most important part of the characteristic curve of negative material. In the lower

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part of the curve, the section B-A, this proportionality is absent, and the increase in the blackening of the layer lags markedly behind the increase of the exposures to which it is due. This section of the curve is usually called the region of underexposures.

There is likewise no direct proportionality between the optical densities and the logarithms of the exposures in the upper part of the curve, the section B-C. This section is termed the region of overexposures. As in the region of underexposures, the increase of optical density of blackening of the photographic layer in this section lags behind the increase of the exposures to which it is due.

From the point of view of exposure measurement, the form of the characteristic curve is of great interest, for it determines the features of a negative material and the relations between the density of blackening and the exposures responsible.

The value of the initial section of the characteristic curve is particularly important. In some negative materials the length of this section is relati[illegible] and covers a considerable interval of exposures. In this case the linear characteristic curve begins only at the region of relatively great densities of blackening.

In materials with a short and steep initial section, however, the beginning of the linear section of the curve corresponds to relatively low densities. In this connection, the interval of exposures covered by the initial part of the curve in such negative materials is very short.

The Contrast Factor

In working on different negative materials, the contrast of the objects photographed are differently reproduced. This is explained by the fact that the increase of the optical density ΔD (Fig.2), corresponding to one and the same increase of exposure, and consequently, the contrasts of the photographic images obtained with different sensitive materials, substantially differ from each other.

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These features of different negative materials, closely connected with the development conditions, are expressed by the value of the contrast factor of the sensitive layer, which is one of its most important characteristics.

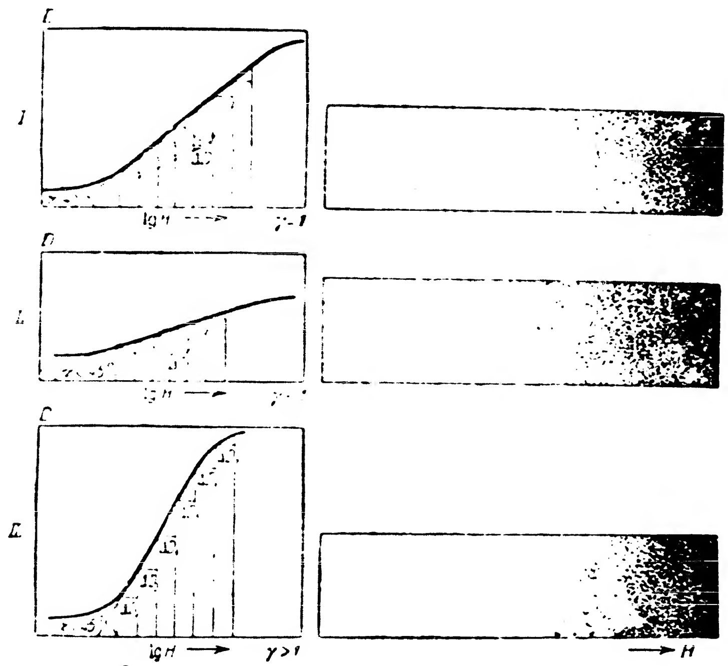

Fig.2. Contrast Factor of Different Photographic Materials.

Numerically, the contrast factor, which is usually denoted by the Greek letter gamma (γ), may be expressed by the ratio of the difference of two adjacent optical densities, taken on the linear part of the curve, to the difference of the corresponding logarithms of exposure. The contrast factor is equal to the tangent of the angle of inclination of the linear part of the characteristic curve to the abscissa axis (with the abscissa and ordinate axes on the same scale).

If the angle of inclination of the linear part is equal to 45°, then the tangent

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of this angle is unity, and consequently the contrast coefficient is also unity. In this case, all differences in the brightness of individual elements of the photographed object will be exactly reproduced in the negative, and to the increments in the value of log H will correspond the same differences of optical density (Fig.2,I).

The requirement that the value of the contrast factor of the negative shall be unity would be correct only if the negative were the ultimate object and the sum of the whole photographic process. In reality, however, the negative is merely an intermediate stage in the production of the final photographic image, and it is from this final image that we must demand the proportional reproduction of the contrast of the photographed objects.

On decreasing the angle of inclination of the linear section within the limits of the normal exposures, the proportional reproduction of the brightness of the object is maintained. In this case the value of γ is less than unity, and a proportional decrease in the difference between the brightnesses of the object may be noted in the negative image (Fig.2,II).

When the angle of the linear section is increased, and the value of $\gamma > 1$, the proportionality of reproduction of the brightness of the object in the negative is maintained, but the contrast proves to be exaggerated (Fig.2,III).

A reduction in the contrast of the negative image is compensated in the positive process by using positive materials of higher contrast. In this connection, negatives are in most cases developed to a γ less than unity. Moving picture negatives are usually developed to $\gamma = 0.65-0.70$ and the negatives of miniature cameras to $\gamma = 0.$[illegible].

In addition to the properties of the negative material, the time of development and the character of the action of the developers used also exerts a great influence on the value of γ, and consequently on the features of the reproduction of the contrast of the photographed object in the negative. With increasing development time, the optical densities corresponding to one and the same increment of exposure are in-

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creased, and the contrast of the image likewise increases. With further lengthening of the development time, the growth of the value of γ slows down, and when a certain maximum contrast has been reached, which differs for different sensitive materials, this increase stops entirely.

Photographic Width

An important property of negative material is their power directly to reproduce, with one and the same degree of contrast, all the differences and relations in the brightness of the objects photographed. This is possible only where the values of the exposures for individual equally-bright elements of the photographed object does not go beyond the boundaries of the region of normal exposures.

Let us consider the characteristic curve in Fig.1.

The projections of the two extreme points of the linear section of the curve, i.e. of the points A and B, intersect the axis of the logarithms of the exposures at the points a and b. For the negative material under study the values of the exposure corresponding to these points are [illegible] and [illegible] and the ratio between them is 1 : 128.

This ratio between the minimum and maximum limits of normal exposure, corresponding to the beginning and end of the linear section of the curve, thus characterizes the difference in brightness of the individual elements of the photographed objects, which can be correctly reproduced by the given sensitive layer and are defined by the concept of photographic width.

Numerically, photographic width may be expressed either directly, by the ratio of the exposures corresponding to the beginning and end of the linear section, or logarithmically, in the form of the difference of the logarithms of exposure. In our example, the tests of a negative motion picture film of type A (Fig.1), these quantities had the ratio of 8 : 1024, or 1 : 128. In logarithmic expression, the photographic width of our material is equal to 2.1.

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The technique of determining the photographic width of multi-layer color films, like the technique of determining their sensitivity, has not yet been adequately developed.

In practice, the photographic width of color negative materials for light of a definite spectral composition, may be approximately estimated from the value of the interval of exposures giving undistorted reproduction of the color of the objects photographed. For most color films, the photographic width is low, and does not exceed 1 : 32-1 : 64.

It must be noted that the photographic width is inconstant, even for a given specific sensitive material; it is obvious that when the development time varies, and the contrast factor varies with it, within certain limits, the photographic width of the sensitive layer will likewise vary (Fig.3).

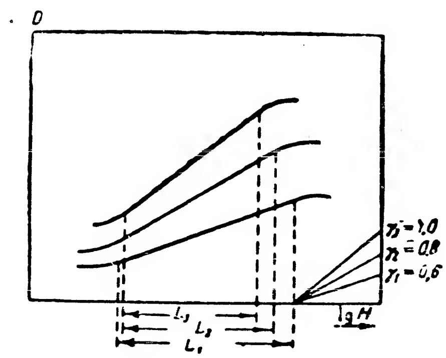

Fig.3. Variation of Photographic Width of Negative Material in Connection with Increased Exposure Time.

The photographic width of white-black negative materials produced in the USSR is very great, and in most cases assures satisfactory reproduction on the photograph even for very high-contrast objects. Soviet motion picture negative films have a

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particularly large photographic width, which goes as high as 1 : 128–1 : 256 and higher.

In spite of this, in photographing objects particularly high in contrast, the illuminations produced on the sensitive films by the optical images of the darkest and brightest elements of the subject being photographed are in many cases beyond the limits of the illuminations corresponding to the beginning and end of the linear section of the curve. In this connection, even exposures corresponding to the brightness of the darkest and brightest elements of the subject often fail to fit into the interval of exposures corresponding to the extreme points of the linear section of the characteristic curve. For this reason, in practice, alongside of a region of normal exposures, a few regions of underexposures and overexposures are also used without appreciable damage to the quality of the image. Obviously the limits of utilization of these regions are determined by the power of the sensitive layer likewise, and for these sections separately, and with adequate accuracy, to reproduce on the negative, the difference in the brightness of the individual elements on the object photographed. Let us consider this in more detail.

The Minimum Useful Gradient

As the exposure decreases, the steepness of the slope of the curve in the region of underexposures decreases more and more, and the contrast is reduced (Fig._). The increments of density corresponding to one and the same increment of exposure likewise diminish. On further decrease of exposure, the contrast, decreasing even more, reaches the point H_{min}, a certain minimum value, beyond which the details in the shadows of the object can no longer be satisfactorily be distinguished. With a still further reduction in the exposure, to a level corresponding to the point D of the curve, the layer becomes completely unable to reproduce separately the differences of brightness.

It is therefore necessary to establish the minimum useful slope of the curve, or,

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as they say, the value of the minimum useful gradient assuring satisfactory reproduction on the photograph of the details in the shadows of the object. This value (Fig.4) may be quantitatively represented by the tangent of the angle of inclination of the tangent to the logarithmic axis of exposures.

Studies have shown that the value of the minimum useful gradient is determined

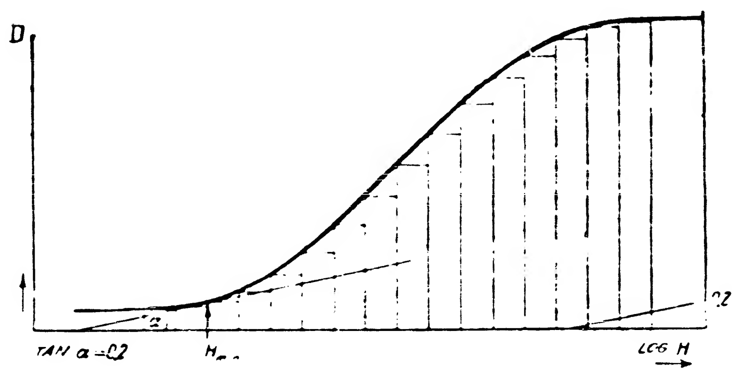

Fig.4. Characteristic Curve of Negative Material. At the Point H_{min} the Minimum Useful Slope of the Curve (Minimum Useful Gradient) is Equal to 0.2.

by many features of the process of photographic reproduction of the tones, and cannot be established on the basis of an analysis of the properties of the negative materials by themselves. A study of motion picture of negatives and positives, and also of still pictures, has shown that the value of the minimum useful gradient for the regions of underexposure may be taken with sufficient accuracy as equal to 0.2.

The Useful Photographic Width

While in this connection, by analogy with the point H_{min} (Fig.5) located in the

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region of underexposures, the point H_{max} is taken in the region of overexposures, with a gradient likewise equal to 0.2, within this section itself, the gradient of any point of the characteristic curve will exceed the value 0.2. In this connection we are able to establish the values of the useful intervals of exposures, or the useful photographic width determined by the ratio of the exposures corresponding to the

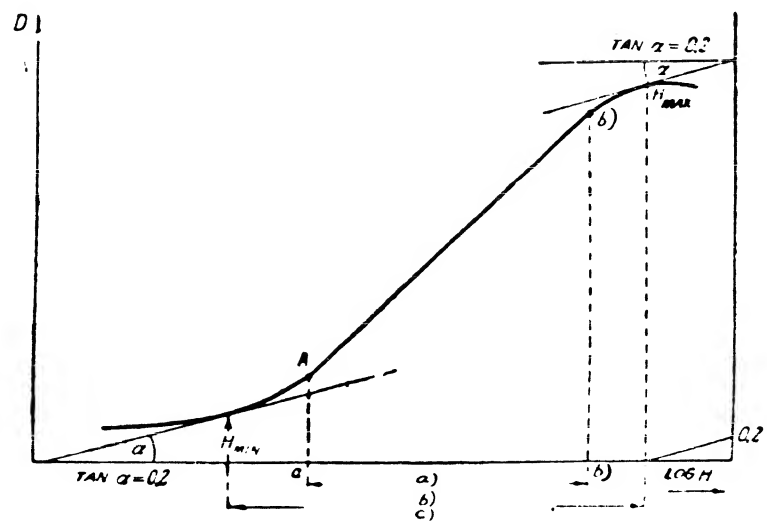

Fig. — [illegible] photographic [illegible] sensitive material

a) Photographic latitude [illegible] useful interval [illegible] exposures; c) [illegible] useful photographic latitude [illegible]

points H_{min} and H_{max}. The latitude of sensitive materials used in practice is somewhat increased in this case, owing to certain sections of the regions of underexposures and overexposures.

Obviously, beyond the limits of the exposure intervals corresponding to the useful photographic latitude, a satisfactory reproduction on the negative brightness differences and all details in the lights and shadows of the object is impossible.

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Let us consider this on the example of a photograph of a subject, the brightness of the brightest element of which, under the given conditions of illumination, is equal to B_{max}, while the brightness of the darkest element equals B_{min}.

The interval of brightness of this object is determined by the ratio between maximum and minimum brightness of individual elements of equal brightness of the object being photographed, and in this case will be equal to

$$\frac{B_{max}}{B_{min}}.$$

Let us assume that the optical image of the darkest area of the photographed object formed by the lens, whose brightness is equal to B_{min}, produces the illumination E_{min} on the sensitive layer, while the optical image of the brightest element, whose brightness is equal to B_{max}, produces the illumination E_{max}.

Then, with the exposure time t, the sensitive layer will have a series of quantities of illumination (exposures) which will lie within the limits $H_{min} = E_{min} \times t$ and $H_{max} = E_{max} \times t$.

After development, in accordance with the values of the exposure H_{min} and H_{max}, optical densities of blackening corresponding to D_{min} and D_{max}, which will be equal for this case, will be produced on the sensitive layer.

Minimum Correct Exposure Time

The points corresponding to the measured densities D_{min} and D_{max} may be marked on the curve of Fig.6 as the points A and B. If the exposure time t is so selected that the point A is located at the lower bend of the characteristic curve within the limits of the useful photographic width (determined allowing for the minimum useful gradient, taken as equal to 0.2), then we may speak of the quantity t as the minimum correct exposure time of the given subject under the given specific conditions of illumination.

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In a case where at the same minimum correct exposure time of t, the point B on the characteristic curve corresponding to the quantity H_{max} is within the boundaries of the useful photographic latitude, all illumination contrasts of the elements of the optical image will be satisfactorily reproduced in the negative.

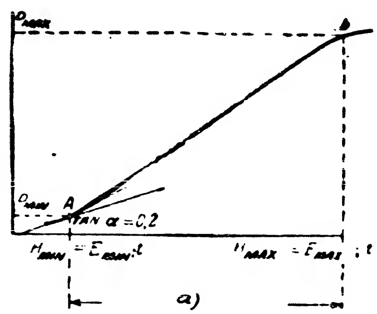

Fig. [illegible] – Minimum Correct Exposure Time

a) Useful photographic width

Let us test this on the analysis of a concrete example from photographic practice. Figure [illegible] gives a photograph made by press photographer [illegible], entitled "Morning [illegible] Square", while Fig. [illegible] gives the negative of this photograph. Let us measure the optical density of blackening of the sensitive layer at different areas of the negative and plot them in the axis of [illegible] characteristic curve shown in Fig.1.

The minimum optical density of this negative is [illegible]. (the shadow side of the [illegible]), while the maximum density (on the brightest area of the sky, to the right of the cathedral) is 1.[illegible] (Fig.9).

The optical densities of all remaining image elements lie within the limits of these minimum and maximum densities.

On the basis of the data of Table 1 and of the characteristic curve in Fig.10, we may note that both the minimum and maximum optical density lie within the limits of the useful photographic latitude of our negative material.

In connection with this, all the brightness differences of the individual elements of the subject are reproduced on the photograph with sufficient accuracy, and the details are fully preserved in the shadows and highlights of the negative.

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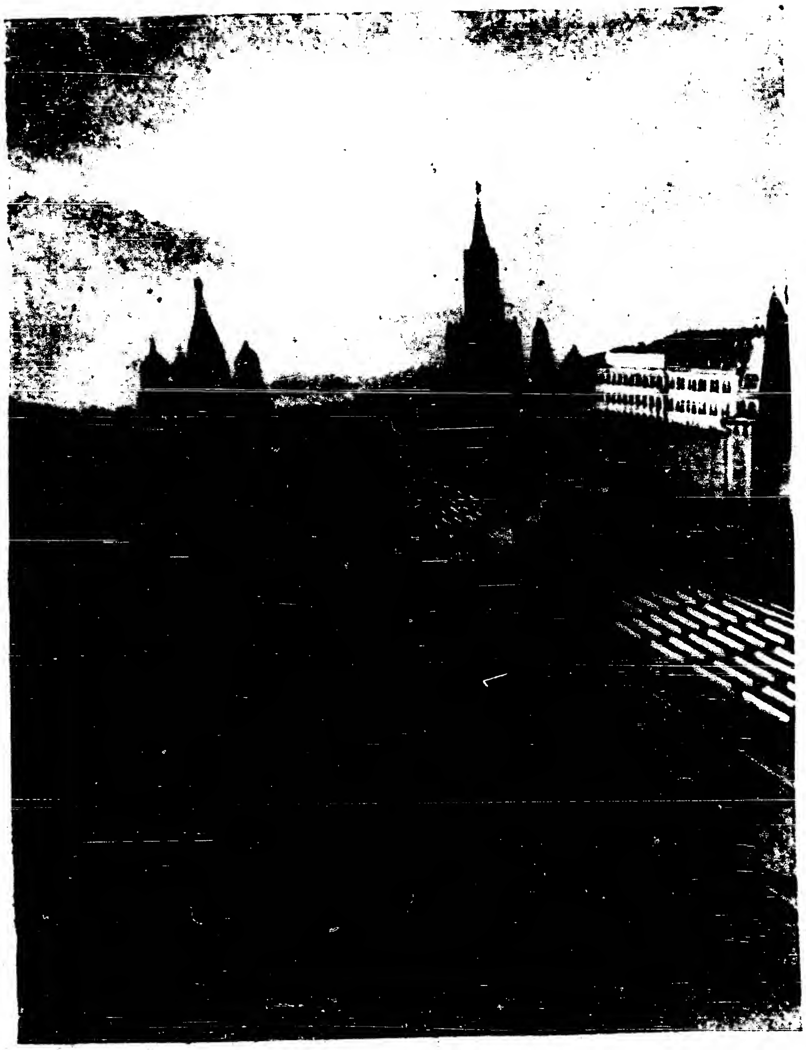

Fig.7a "Morning on Red Square". Photographed by A.Garanin.

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Fig.8. Negative of A.Garanin's Photograph (cf.Fig.7).

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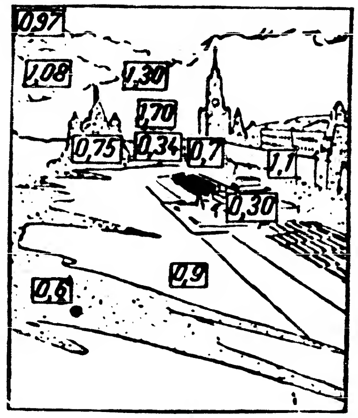

Fig.9. Distribution of Areas of Optical Density on Negative.

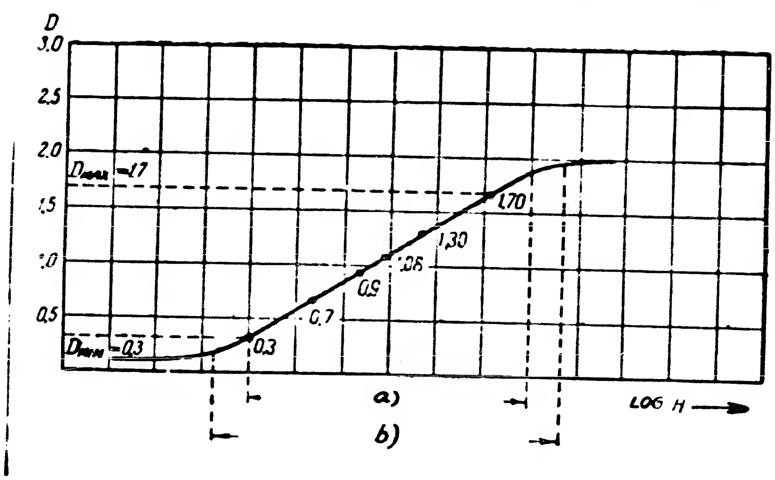

Fig.10. Characteristic Curve of Negative Material. The Points Corresponding to the Optical Densities of the Principal Areas of the Negative of the Photograph Shown in Fig.7 are Marked.

a) Photographic width; b) Useful photographic width determined with allowance for the value of the minimum useful gradient = 0.2

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From the above the conclusion may be drawn that in photographing subjects with relatively small brightness intervals, we shall be able to satisfactorily reproduce all the brightness relations on the photograph only if the conditions of exposure are so selected that the exposures corresponding to the weakly illuminated shadows of the object photographed and to its brightest high lights lie completely within the boundaries of the useful photographic width of the negative material.

Figure 11 gives a photograph of a holiday illumination of the building of the Moscow Soviet. The contrasts of the subject are very high. As in the preceding case, we measure the optical densities on the negative of this photograph and plot them on the characteristic curve shown in Fig. 12. The minimum optical density D_{min} of the negative is equal to 0.17 (the figures in the foreground), while the maximum (the bright details of the illuminated building), i.e. D_{max}, equals 1.9[illegible]. In this case both the minimum and the maximum densities of the negative go beyond the limits of the densities corresponding not only to the linear section of the characteristic curves, but even the useful photographic width of the negative material. In this connection the details have completely disappeared in both the shadows and the high lights of the negative.

In this case, all the contrasts of the object photographed cannot be correctly reproduced on the negative no matter how long the exposure time.

However, in photographing the majority of subjects with the usual small brightness ranges, the correct reproduction of all the different degrees of brightness is possible even at somewhat different exposure times.

Allowable Error in Determining the Exposure Time

A comparison of the values of the brightness interval of the object photographed and the photographic width will be necessary to solve most problems of exposure measurement connected with the direct determination of the time and conditions of exposure. For this reason we must elucidate the relationship between the allowable

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limit of error in determining the exposure time, the photographic width of the negative material, and the interval of brightness of the objects photographed.

The limit of error in determining the exposure time may be numerically determined by dividing the useful exposure range, i.e. the useful photographic width of the negative material, by the value of the brightness range of the subject.

It is obvious that with increasing photographic width of the negative material the allowable limits of error in the determination of the exposure time will increase, but will decrease with increasing brightness range of the photographed object.

In this connection the allowable errors in the determination of the exposure time do not exceed a factor of 1.5 to 2 for high-contrast objects whose brightness range approaches the photographic width of the negative material used. In photographing objects of very high contrast, which, in some cases is more than the width of the material, the required accuracy of determination of the exposure time increases still more.

In working with color multi-layer films, in connection with their small width, these requirements become stricter, even in taking subjects with relatively low contrast. For most subjects taken on black and white negative materials under the conditions of natural illumination, however, the allowable errors in exposure determination reach a level of 4-6 times.

The allowable error of exposure are particularly high in photographing low-contrast objects with a brightness range of 5 : 1 to 10 : 1. In these cases the allowable errors are sometimes as great as 20 or 30 times.

Let us verify this on the analysis of a few examples from photographic practice.

The photograph (Fig.13) was made on a sunny winter day. The contrast of the subject is very high. The brightness of the least bright area of the object (the dark figures) is 110, and that of the brightest area, the sky, is 46,000 apostilbs, i.e. the brightness range is about 450 : 1. Nevertheless, as a result of a rather precise determination of the minimum correct time of exposure, the details come out

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well in the shadows. All details in the highlights of the negative also are fully preserved. In connection with the very low brightness of the figures, taken against the light, the density of the negative in these areas is lower than the necessary minimum densities, and the details on these areas are missing. The brightness range of this subject somewhat exceeds the useful photographic width of the material. For this reason, even with a precisely determined exposure time, only the densities of the medium bright elements of the object will correspond to the linear section of the curve (Fig.14). Other, less bright areas are underexposed. In this case, by increasing or decreasing the exposure, we only shift the whole scale of the brightness of the object towards the region of underexposure or overexposure, as the case may be.

In photographing similar very high-contrast subjects, no deviation at all from the accurately determined exposure time, assuring the optimum results, can be allowed.

The photographic portrait of the child in Fig.15 might be taken by the light of two photographic bulbs, 275 and 500 Watts. The brightness range of this object is small, and is about 14 : 1. Let us measure the optical densities of blackening on the individual areas of the negative of this photograph and plot them on the axis of optical densities (Fig.16). The minimum optical density of this negative is 0.40, and the maximum 1.15. The exposure time for a lens stopped down to 1 : 4.5 is 1/10 sec. With this exposure time, all the brightnesses of the object fit fully within the limits of the photographic width of the negative material.

In connection with the small interval of brightness of the object, the exposure time could have been (cf.Fig.16) reduced to 1/15 sec or lengthened to 1 1/2 sec without appreciable damage to the quality of the photograph. In spite of the variation in the total density of the negative, in both these cases all the brightness differences of the individual elements of the object were reproduced rather correctly. The allowable errors in determining the exposure time in photographing similar subjects are relatively great and may fluctuate in rather wide range.

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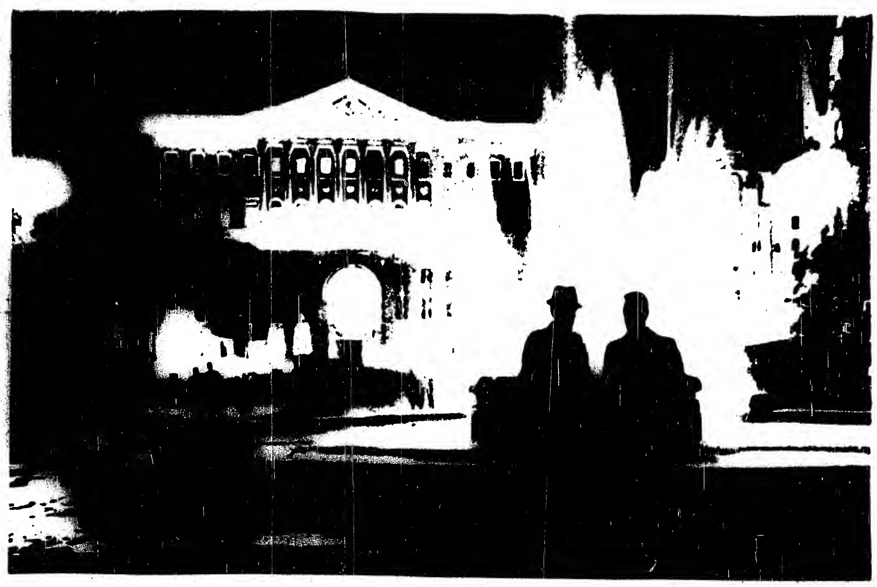

Fig.11. Building of Moscow Soviet with Holiday Illumination. (photographed by G.Mozer).

The Contrasts of the Objects Photographed are very High.

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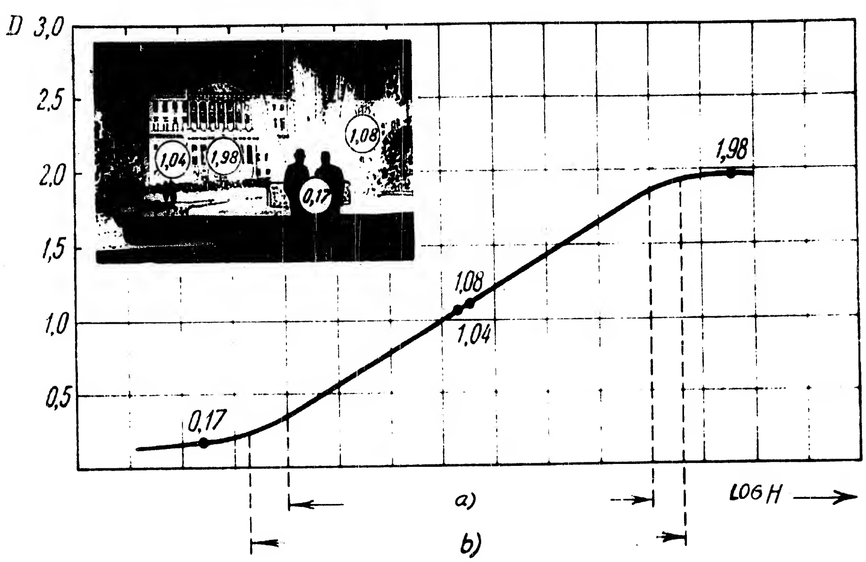

Fig.12. Characteristic Curve of Negative Material.

The Points Marked Correspond to the Optical Densities of the Principal Areas of the Negative of the Photograph on (Fig.11).

a) Photographic width; b) Useful photographic width, determined allowing for the value of the minimum useful gradient = 0.2.

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The photograph shown on Fig.17 was made on a cloudy winter day during a fog. The exposure was 1/50 sec with a stop of 1 : 3.5. The object is low in contrast, since the fog filling the space between the object of the photograph and the camera had almost no effect on the brightness of the light elements of the subject, but substantially increased the brightness of the darkest areas. In connection with

Fig.13. Passage Under Arch. (Photo by Ye.Kryakvin). The Brightness Range of the Photograph is About 450 : 1.

this fact, the brightness range of the object is very low (about 5 : 1) and is considerably lower than the photographic width of the negative material used. In this case, too, the negatives obtained at various exposures (within the limits of the useful exposure range) will differ among themselves only in density, but the contrasts of the object will be reproduced in the same way on all these photographs.

The photographic width of the negative material used in for the photograph is 1 : 128. The brightness range of this object was 5 : 1. The allowable limit of er-

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ror in determining the exposure time will be expressed by the ratio 128 : 5, i.e. it will be about 25. This conclusion is completely confirmed by experiment. Thus, if

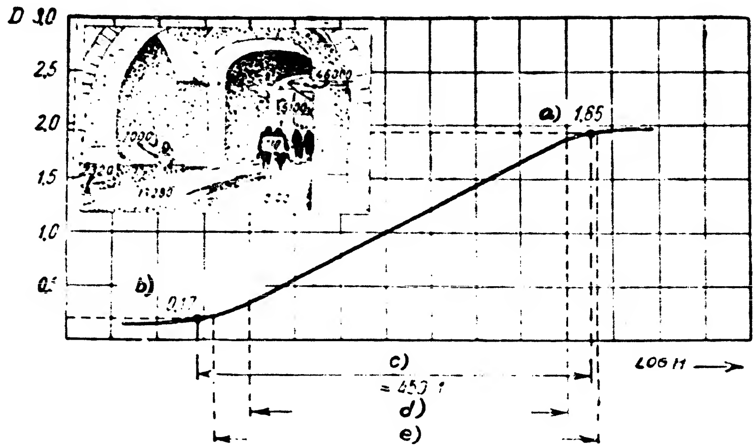

Fig.14. Characteristic Curve of Negative Material. The Points Marked on this Curve Correspond to the Minimum and Maximum Optical Densities of the Negative of this Photograph.

a) Sky; b) Dark figures; c) Brightness range of object; d) Photographic width 128 : 1 → ; e) Useful photographic width, determined after allowing for the value of the minimum useful gradient = 0.2.

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at exposure 1/50 sec, the minimum density of the negative is 0.4 (the dark figures in the foreground), and the maximum is 0.82 (the bright parts of the sky), then when the exposure is increased 25 times, i.e. to 1/2 sec, the densities of the same areas of the negative are increased respectively to 1.4 and 1.82, but the contrasts of the image, as will be clear from Fig. 18, remain unchanged.

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Fig.15. Portrait of a Child. Brightness of this Object is not Great and is about 14 : 1. (Photo by O.Avdeyev).

The Minimum Useful Negative Density

The problem of the exact determination of the minimum correct time of exposure is closely connected with the establishment of the minimum useful density of the neg-

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ative. In addition to the relation between the quantity of illumination acting on the sensitive layer and the densities produced as a result of exposure and development - a relation that has already been discussed - it is also necessary to dwell on

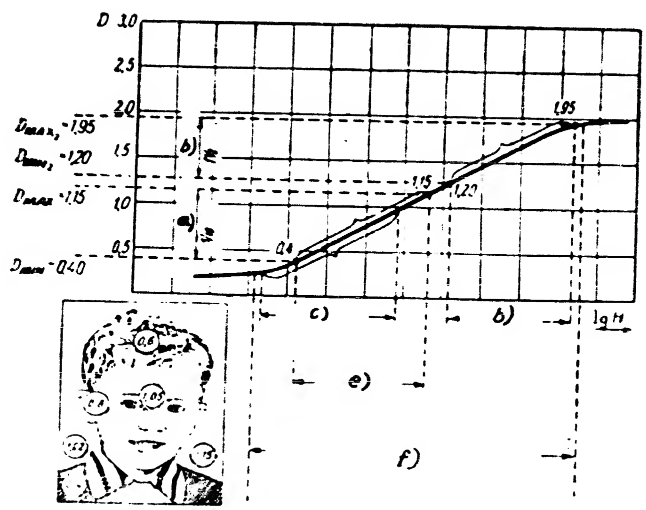

Fig.14. Exposure Time in Taking the Portrait Shown in Fig.15, in View of the Small Brightness Range of the Object, Could be Shortened to 1/15 sec or Lengthened to 1 1/2 sec without Damaging the Quality of the Picture.

a) On exposure of 1/10 sec; b) On exposure of 1 1/2 sec; c) Brightness range of object. Exposure 1/15 sec; d) Brightness range of object, Exposure 1 1/2 sec; e) Brightness range of object, Exposure 1/10 sec; f) Useful photographic width determined after allowing for the value of the minimum useful gradient = 0.2.

the influence exerted by the features of the negative material on the value of the

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minimum useful density.

If the region of underexposures for a given sensitive layer is small and the characteristic curve has a short and steep initial section, then the value of the

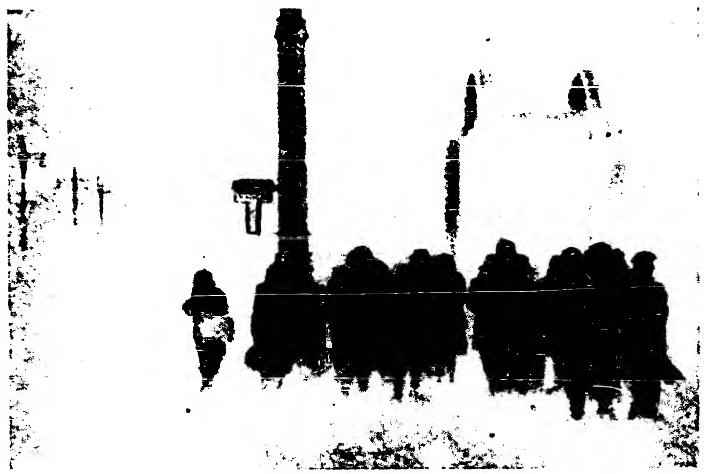

Fig.1[illegible]. Winter Day. Photograph Made in Cloudy Weather. Brightness Range of Object Very Small, About 5 : 1.

smallest useful density D_{min}, and consequently also that of the corresponding minimum correct exposure time t_{min}, will also be relatively small.

For a different negative material with a larger region of underexposures, i.e. with an elongated initial area, the value of the minimum correct exposure time t_2 under the same conditions of exposure and development will already be different. In this case, as shown in Fig.19, the value D_{min} (for a negative material corresponding to the curve with a large region of under exposure) will be considerably greater, and it may be found that the exposure time in the second case is too great. In reality, however, even in such a case, this will completely satisfy our definite minimum correct exposure time.

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The practical value of the accurate determination of this minimum negative density is particularly great in color photography, and in photographing objects distinguished by very small details. In these cases, in connection with the considerable

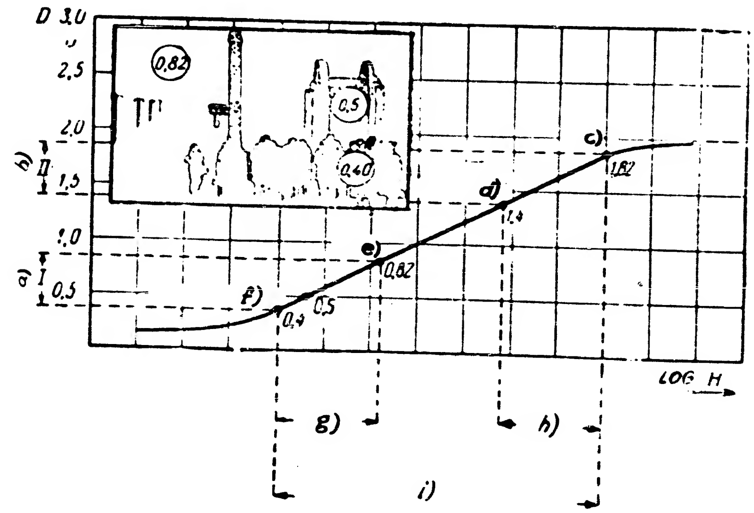

Fig.1 . Allowable Limit of Error in Determining the Exposure Time for the Subject Presented in Fig.[illegible].

a) At exposures 1/50 sec; b) At exposure 1/2 sec; c) Sky; d) Dark figures; e) Sky; f) Dark figures; g) Brightness range of object, Exposure 1/50 sec; h) Brightness range of object, Exposure 1/2 sec; i) Photographic width 12[illegible] : 1

scattering of light in the emulsion layers, leading to a lowering of the resolving power of the negative material, the best results are attained at the lowest possible values of D_{min}. The exposure time for such photographs must approach the exact value of the minimum correct exposure determined after allowing for the useful photo-

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graphic width of the negative material. In the case of failure to satisfy this requirement, and the still greater lowering of the value of D_{min}, i.e. of the minimum useful density, beyond the limits of the lower boundary of the useful photographic width, the necessary proportionality of reproduction of the difference of brightness in the shadows of the object is impaired. Obviously at still greater reductions in

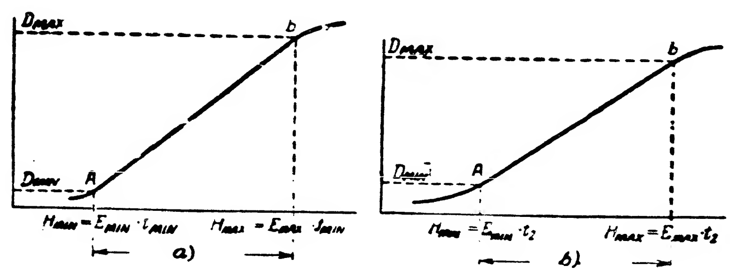

Fig.19. Utilization of Region of Proportional Region of Contrast Using Negative Materials with Different Underexposure Regions.
a) Useful photographic width; b) Useful photographic width.

the negative density, i.e. at underexposures, the contrast on the darker areas of the image will cease to be distinguishable, and the details in the shadows will disappear.

An example of this may be given in the photograph of the architectural monument in the village of Kolomensk, near Moscow. This picture was made on a negative film with a characteristic curve of having a large initial section. The exposure time was so selected that the density of the dark parts of the negative corresponding to the least bright elements of the photographed object were smaller than the minimum useful density. This led to the complete disappearance of detail in the shadows of the picture. For this reason, these features of the negative materials used must also be taken into account in determining the exposure time, and the minimum correct

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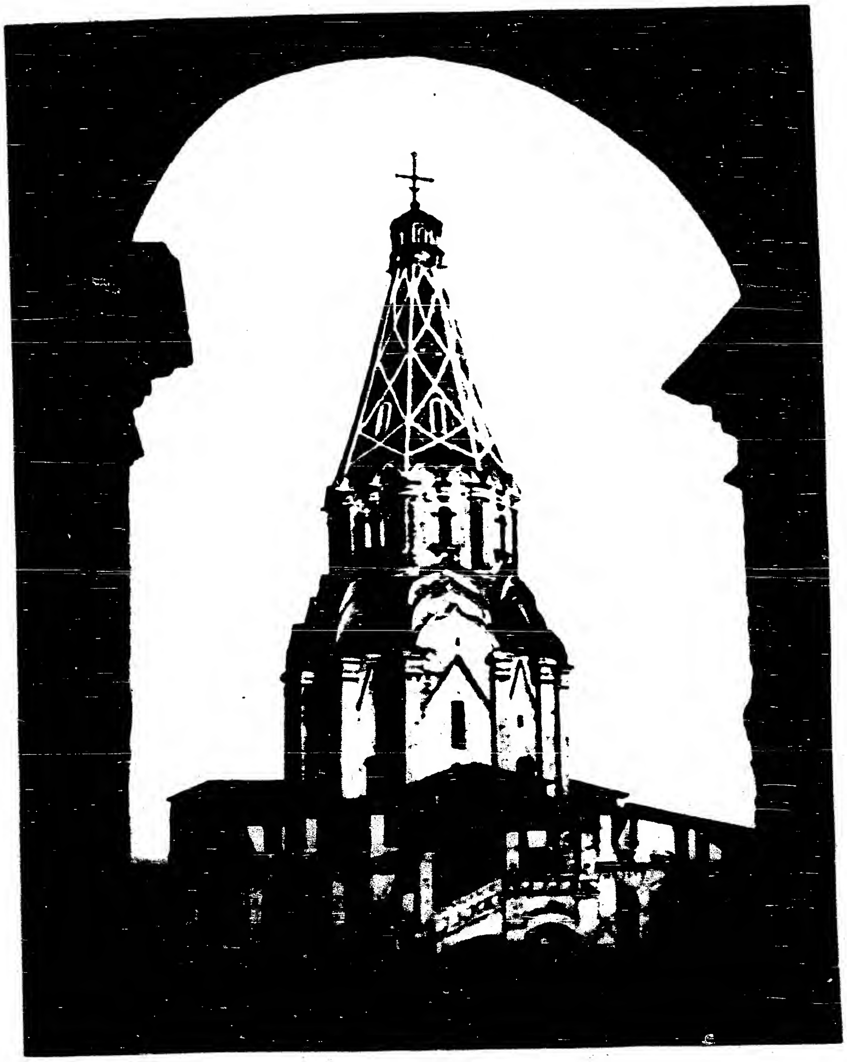

Fig.20. In Kolomensk Village. This Picture was Underexposed.

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exposure that can assure the most complete utilization of the useful exposure interval (Fig.21) should be made.

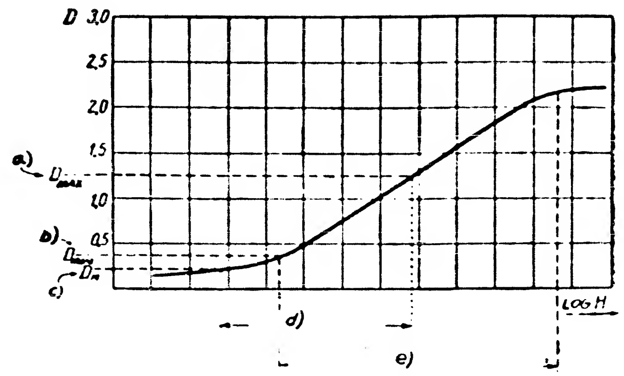

Fig. 21. The Curve Shows that the Density of the Shadow Parts of the Negative is Less than the Minimum Useful Density.

a) Maximum density of highlights of negative; b) Minimum Useful density; c) Density of Shadow parts of negative; d) Brightness range of object; e) Useful photographic width determined after allowing for the value of the minimum useful gradient equals 0.2.

THE PRINCIPAL FACTORS AFFECTING THE VALUE OF THE EXPOSURE

Exposure Measurement Characteristics of Photographed Objects

From the standpoint of exposure measurement, photographed objects on the whole are characterized by illumination, spectral composition of the illuminating light, character of surface, and color of the objects photographed.

The optical properties of the medium between the photographed object and the camera also exert substantial influence on the exposure-measurement characteristics

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and the final quality of the image.

Since the light rays coming from the photographed object and passing through the lens of the camera act on the sensitive layer of the negative material, it follows that in addition to the influence of other numerous factors, which will be considered below, the illumination of the individual elements of the optical image is determined primarily by the brightness of the regions of the object corresponding to it.

The Reflection Factor

The brightness of one area or another of the object photographed is determined by its illumination and power to reflect the light rays falling on it. The reflect-

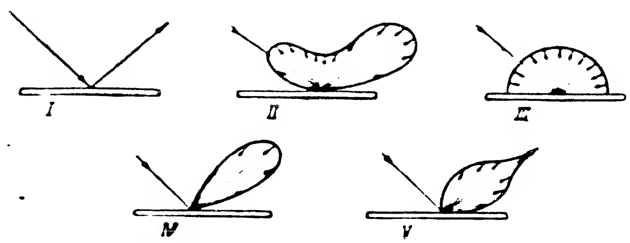

Fig.22. Curves of Brightness Distribution for Various Forms of Reflection:

I- Mirror; II- Scattered; III- Diffused; IV- Directional-Scattered; V- Mixed.

ing power of various objects fluctuates over a rather wide range and is usually characterized by the reflection factor of the surface, which determines the ratio of the light flux reflected by a body to the light flux falling on it.

The peculiarities of the textures of the surfaces reflecting light determine not only the magnitude and character of the light flux reflected but also its direction.

In this connection, three main forms of reflections are distinguished:

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directional, scattered, and mixed.

The directional, or mirror reflection characteristic of smooth polished surfaces, is represented schematically in Fig.22.

In a scattered reflection the light flux is scattered in various directions. Two frequent cases of scattered reflection must be noted: diffuse and directional-diffuse. The materials possessing directional-diffuse reflection include, for example, dull metal surfaces. The surfaces having diffuse reflection include rough stuccoed surfaces, cement coating, and similar matte compositions.

Mixed reflection, characterized by the combination of directional and scattered reflection, is likewise schematically represented in Fig.22.

The figure distinctly shows the relation of the brightness of these surfaces, which reflect light differently, and the direction of observation.

The brightness is one of the basic photometric quantities and characterizes the luminescence of light sources and of illuminated surfaces. Brightness is directly perceived by the eye, and if the medium is transparent, its value depends on the distance from the observer's eye. The unit of brightness is the stilb, which is equal to the brightness of a uniformly emitting plane surface which emits light, in a direction perpendicular to it, of the strength of one candle per square centimeter. In exposure measurements and calculations, the unit of brightness of a surface obeying Lambert's law is often taken as the apostilb, or "lux on white": one stilb = 31,400 apostilbs.

Table 2 gives data on the brightness of a few objects.

The textures possessing primarily directional-scattered and mixed reflection, include the surfaces of very many photographed objects. When these textures are observed from different points of view, their brightness (at one and the same illumination) will vary over rather wide range. The brightness of these surfaces will be maximum in the directions approaching the angles of mirror reflection.

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The Coefficient of Brightness

Since it is precisely the value of the brightness in the direction of the camera that determines the exponometric brightnesses of photographed objects and the corresponding illuminations of the optical image, we are primarily concerned, in calculating exposures, with the data on the value of the brightness of objects photographed, measured in the direction of the camera. In this connection the peculiarities of the reflection of light by one surface or another may be expediently expressed by the value of the brightness coefficients, determined by the ratio between the brightness of this texture in the given direction to the brightness of an absolutely white surface illuminated in the same way*.

Table 2

Approximate Values of the Brightness of a Few Objects

Object	Value of Brightness
Sun, observed from the surface of the earth with a clear sky	150,000 stilbs
Absolutely white matte surface illuminated by sun (illumination 100,000 lux)	3.2 stilbs
Snow under direct sunlight	80,000-90,000 apostilbs (about 3 stilbs)
White paper illuminated by direct sunlight	40,000-60,000 apostilbs
White paper in shade on a sunny day	7,000-10,000 apostilbs
White paper on a cloudy day on an open space	10,000-13,000 apostilbs
Light colored building faced with ceramic tile, in sunlight	25,000-30,000 apostilbs
Dry asphalt in sunlight	11,000-17,000 apostilbs

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* An absolutely white surface is a surface which diffusely reflects 100% of the light falling on it, and whose reflection factor is accordingly taken as unity.

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Object	Value of Brightness
Dry asphalt in shade	2,500- 4,000 apostilbs
Water surface in sun (in the light)	3,500- 5,000 apostilbs
Grass in sun	[illegible],000-10,000 apostilbs
Face in sun (measurement of integral brightness)	14,000-20,000 apostilbs
Face in overcast weather (measurement of integral brightness)	3,000- [illegible],000 apostilbs
Face with black and white picture, in motion-picture studio under [illegible] lux illumination	250- [illegible] apostilbs
Face for color photography in motion-picture studio under illumination of the order of [illegible] lux	1,250- [illegible] apostilbs

Value of Mean Brightness of Heavenly Vault

Under Various Atmospheric Conditions

Object	Value of Brightness
White clouds illuminated by sunlight	Up to 100,000 apostilbs
Sky covered by light cloud	28,000-40,000 apostilbs
Sky average cloudiness	12,000-16,000 apostilbs
Sky in overcast weather	2,000- 5,000 apostilbs
Sky in very overcast weather	1,000- 3,000 apostilbs
Sky on usual cloudless day	6,000-10,000 apostilbs
Sky on very clear day	3,000- 5,000 apostilbs

The brightness of a surface when there is a appreciable directional reflection is determined not only by the illumination of the surface, but, depending on its reflection of the light source itself, it also becomes a function of the brightness of that light source. The brightness factor of colored surfaces, which selectively reflect the light fluxes falling on them, will substantially vary with the spectral

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composition of that light.

The Spectral Brightness Factor

For this reason, in determining the conditions of exposure, the values of the spectral brightness coefficient of their surfaces must be thoroughly taken into account. But in practice, in determining the time and conditions of the exposure by the aid of photoelectric instruments, all of the extremely complex interrelations between the colority of the objects photographed, the variations of the spectral composition of the illuminating light, and the color sensitivity of the negative materials cannot be completely taken into account. Nevertheless, the exposure determined in practice by means of exposure meters are still able to consider the values of the measured brightness of the colored object being photographed as a certain aggregate of their brightness characteristics.

The Brightness Range of Photographed Objects

As shown in Table 3, the reflecting power of different objects fluctuates over a rather wide range. Surfaces possessing the maximum reflecting factor, such as those coated with magnesium oxide, reflect up to 96% of the light falling on them, while black velvet reflects only 1 to 3%. For this reason the maximum possible range of brightness for a uniformly illuminated object cannot in practice exceed 90:1. The brightness range between similarly illuminated surfaces of freshly fallen snow, which reflect up to 78% of the light falling on it, and black velvet, is equal only to about 50:1. By shading the areas covered with black velvet, however, and maintaining the illumination of the snow surface, we may increase the brightness range of this object to a very great extent. With increasing difference of illumination between the individual elements, the brightness range of photographed objects may be increased to immense values, reaching 100,000:1 and even more.

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Table 3

Reflecting Power of Various Surfaces

Surface	Form of reflection	Reflection coefficient
Magnesium oxide	Diffuse	0.96
Alabaster	Diffuse	0.92
Polished silver	Directional	0.88–0.93
Matte silvering	Directional-scattered	0.7
Glass mirror	Directional	0.72–0.85
Chromium-plated polished surface	Directional	0.60–0.70
Matte chromium plating	Directional-scattered	0.50
Polished aluminum	Directional	0.65–0.75
Matte aluminum	Directional-scattered	0.55–0.60
White tinplate	Directional	0.66–0.69
Freshly fallen snow	Mixed	0.75–0.78
Thawing, clean snow	Mixed	0.60–0.62
Matte white paper	Directional-scattered	0.6–0.7
White plaster surface	Diffuse	0.85
White cement coating on stucco surface	Approaches diffuse	Up to 0.8
Stucco surface	Diffuse	0.4–0.45
Skin of face	Mixed	0.25–0.35
White dry sand	Diffuse	0.24–0.32
Wet white sand	Diffuse	0.11–0.2
Yellow clay	Diffuse	0.16
Asphalt sidewalk, dry	Mixed	0.10–0.18
Asphalt sidewalk, wet	Directional-scattered	0.06–0.08
Dry black earth	Diffuse	0.07–0.08
Wet black earth	Directional diffuse	0.02–0.05

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(table continued)

Surface	Form of reflection	Reflection coefficient
Boards (fresh wood)	The same	0.35–0.42
Old silvered boards	The same	0.12–0.16
Crowns of evergreen vegetation	Diffuse and directional-scattered	0.08–0.12
Deciduous vegetation in summer	Directional-scattered	0.09–0.12
Deciduous vegetation in autumn	The same	0.15–0.30
White silk	Mixed	0.35–0.55
Black cloth*	Directional-scattered	0.1–0.12
Black velvet	Diffuse	0.01–0.03
Black fur	Diffuse	Still less

In photographing most objects we meet not only the pure brightness constrasts, but also the phenomena of color contrast. In these cases the determination of the brightness range is made more complicated by the necessity of taking account not only of the quantitative differences in brightness of these or those elements of the object and the background, but also of the differences in the spectral coefficients of brightness of their colored surfaces.

It is very difficult to establish the values of such a mixed contrast, determined simultaneously by the influence of both brightness contrast and color contrast. The value of the color contrast, in distinction to that of brightness contrast, cannot be expressed by any one quantity, and therefore there is still no simple expression for the measure of color contrast. But since the spectral

* The high absorptive properties of these materials are explained in part by their porosity, which causes the light falling on them, before leaving the interior of the material to be reflected several times.

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sensitivity of photoelectric exposure meters shows a marked approximation to the spectral sensitivity of the eye and of modern negative materials, in the practice of exposure measurements, the brightness ranges of colored objects may be expressed with sufficient accuracy by their brightness ratios determined by the aid of the exposure meter.

As an example we give the mean values of the brightness range for a few of the most usual photographed objects, summarized in Table 4.

Variation of Conditions of Natural Illumination, and the Value of the Brightness Range of the Object

In natural photographs the variation in the character of the illumination connected with altitude of the sun, the variation in the transparency in the atmosphere and of the cloudiness substantially influence the ratio between the directional and scattered parts of the solar radiation. This variation in the character of the illuminating light cannot but influence the character of the photographic image and manifest itself first of all in the contrast of the illumination. The increase in the proportion of scattered light in the total illumination, which intensifies the illumination of the shade areas of the photographed object, markedly reduces image contrast. This reduction in the brightness range of the photographed objects may reach very high levels when there is cloudiness. When the cloudiness increases and the quantity of scattered light rises, the illumination of the elements in the shadow may be doubled or tripled, and even increased by a large factor, while the brightness range of the object is correspondingly reduced.

Table 4

Brightness Ranges of a Few Photographed Objects (According to the Data of the Department of Motion-Picture Photography, VGIK)

Objects photographed	Brightness Interval
Earth's surface seen from aircraft, summer	1:3 - 1:6

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(table continued)

Objects photographed	Brightness Interval
Earth's surface seen from aircraft, winter	1:6 - 1:10
Landscape without foreground, in mist	1:2 - 1:3
Landscape without foreground in scattered light on overcast day	1:5 - 1:10
Landscape without foreground in direct sunlight	1:10 - 1:30
Landscape without foreground taken against the light	1:20 - 1:40
Landscape with foreground in direct sunlight	1:20 - 1:60
Landscape with very dark foreground in sunlight	1:100 - 1:300
Landscape with sun in frame	1:2,000,000
City scene without foreground on overcast day	1:5 - 1:10
City scene without foreground in sunlight	1:10 - 1:40
Narrow shadowed streets with separate buildings illuminated by the sun	1:100 - 1:500
Dark buildings against sky background	1:100 - 1:200
Dark spans and arches of bridges, and gates, with backgrounds brightly illuminated by the sun	1:1000 - 1:10,000
Groups on sunny day, depending on color of clothing and direction of light	1:20 - 1:300
Groups on overcast day	1:10 - 1:60
Portrait with light hair against background of open landscape with sunlight	1:10 - 1:12
Portrait with dark hair against background of open landscape in sunlight	1:20 - 1:100
General layouts in motion picture studio, according to character of subject and illumination	1:10 - 1:50
Inside view of room (without windows, in frame)	1:8 - 1:12
Inner view of light room, taken facing windows, without artificial illumination	1:100 - 1:500
Inner view of dark room taken facing brightly illuminated windows, without artificial illumination	Up to 1:100,000

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A result of this is the very surprising variation of the exposure measurement characteristics and of the character of the images of the objects taken in overcast weather or with a certain, even the very slight whitish haze.

Influence of Mist and Haze

A very appreciable influence on the brightness range of photographed objects is exerted by the optical properties of the medium filling the space between the photographed object and the camera. The brightness of the atmospheric haze or of the translucent mist is, as it were superimposed on the brightness of all elements of the objects photographed. Without exerting a perceptible influence in increasing the brightness of the light areas, it substantially increases the brightness of the dark or slightly illuminated elements of the object. The thickening of the mist and the increases of its brightness, as well as the increase of the distance between the photographed object and the camera, strongly reduces the brightness range of the object. When the density of the haze or mist is further increased, its brightness, after reaching a definite value, levels out with the brightness of the lightest elements of the object. The brightness range of the object of photography in this case will be 1:1, its contrast will fall to zero, and differences of brightness will become imperceptible. The value of the brightness interval of the objects photographed, as we have already noted in the last Chapter, is of very great practical importance, which increases particularly when working on color negative materials and in taking high-contrast subjects. For this reason the method of determining the brightness range of the photographed object by means of photoelectric instruments has therefore become widespread. We shall later consider in detail the technique of determining the brightness range by the aid of photoelectric exposure meters.

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THE ILLUMINATION OF THE SENSITIVE LAYER AND ITS INFLUENCE ON THE TIME AND CONDITIONS OF EXPOSURE

The principal factors determining the illumination of the sensitive layer and consequently, also the value of the exposure required, are the brightness of the objects photographed and the power of the optical system of the camera. At a given brightness of the photographed objects, the illumination of the optical image is directly proportional to the square of the relative aperture of the lens. The exposure time necessary to obtain one and the same photochemical action of the light on the sensitive film will be inversely proportional to the square of the relative aperture.

Relation Between the Illumination of the Sensitive Layer and the Brightness of the Photographed Object

If the brightness of an individual element of the photographed object is known, then the illumination produced, on the sensitive material, by the area of the optical image corresponding to it, is determined by the equation

$$E_{image} = \frac{B_{ob}}{4} \cdot \left(\frac{d}{f}\right)^2$$

where E_{image} = the illumination of the area of the optical image in lux; B_{ob} the brightness of the photographed objects, in apostilbs; d the diameter of the effective aperture, and f the focal length of the lens.

Without allowing for the loss of light in the optical system of the camera and the influence of other factors which substantially lower the illumination of the optical image, this equation can serve only to obtain approximate data on the illumination of the sensitive layer and the value of the necessary exposure. To obtain complete accurate data on the illumination produced at one area or another of the sensitive layer by the optical images of the photographed objects, however, it is necessary to take account of all the main factors which affect that value in one

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way or another. It must be noted that in the practical work of a motion picture operator or photographer, and in the exposure measurements made by them, these formulas are usually not used, since they are very complex. To elucidate the influence of the principal factors determining the illumination of the sensitive layer, it will be expedient to discuss this subject in detail.

Light Losses in the Lens and the Effective Lens Speed

The losses of light when the light rays pass through the lenses are made up of the losses on reflection of light from the surfaces of the lens elements and the absorption of light in the interior of the glass. In this connection, in distinction to the calculated lens speed, which is determined merely by the geometrical dimensions of the effective aperture and focal length, and does not allow for the loss of light in the lens, the so-called actual or effective lens power should be taken into account. The data on the effective lens power characterize the operation of an optical system incomparably more completely, and make it possible to make comparative estimates of the effective speed of lenses of different types.

The light losses by absorption by the glass of the lens usually do not exceed 1% per cm of glass thickness and do not substantially reduce the illumination of the optical image. The influence of this factor for lenses of short focal length may therefore be neglected.

The losses of light resulting from its reflection from the lens surfaces has a considerably greater influence on the value of the effective speed of a lens. The value of these losses increases with the refractive index of the glass and varies from 4 to 6.8%.

With an accuracy sufficient for practical purposes it may be considered that, when light is reflected from each air-glass surface of a lens, about 5% of the light falling on it is reflected. These light losses increase sharply with the number of lens elements and the number of uncemented surfaces, which constitute surfaces of separation between air and glass.

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The Coefficient of Transmission of the Lens

Table 5 gives comparative data on the light losses by reflection for a simple lens, and for optical systems with varying numbers of light-refracting surfaces. In modern compound lenses, with 6 to 8 air-glass surfaces of separation, the total losses from reflection and absorption of light are very great, reaching 30-40% and more. The coefficient of transmission of such lenses, defined as the ratio of the light flux passing through the lens to the light flux falling on it, sometimes does not exceed 0.50-0.60.

The effective speed of compound lenses is very much less than their calculated speed, is very greatly reduced. In this connection, the speed of lenses of different designs cannot be evaluated and compared in exposure measurement calculations without allowing for the coefficient of transmission, and only from the value of the relative aperture and the geometrical lens speed, since this unavoidably leads to errors.

The losses of light in the lens may be approximately determined by the formula

$$K = 0.95^{n} \cdot 0.99^{l}$$

where n is the number of uncemented lens surfaces (the light losses on reflection is taken as equal on the average to 5%), l = length of the path of the ray through the glass of the lens (in cm).

Table 5

Light Losses Due to Reflection in Optical Systems

Number of lenses	Number of glass-air surfaces of separation (index of reflection of glass = 1.55)	Brightness of emerging beam (brightness of pencil of rays falling on lens taken as 1.00)
1	2	0.90
2	4	0.82
3	6	0.75
4	8	0.68

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In recent years, the method of coating lenses, which substantially increases their effective speed, has been widely used to reduce light losses and increase the coefficient of transmission of the camera optical system.

Thus, for example, according to the data of V.V.Pus'kov, the transmission coefficient of the "Yupiter 3" lens with a focal length of 5.0 cm and a relative aperture of 1:1.5, was 72% before coating, while after coating it increased to 91%.

For the "Yupiter 12" lens, with a focal length of 3.5 cm and a relative aperture of 1:2.8, these values are respectively 68 and 89%.

For the "Industar 22" lens with a focal length of 5.0 cm and a relative aperture of 1:3.5, installed in the "Gorkiy" miniature camera, these values are 69 and 90%.

The illumination of the photosensitive layer produced on various areas of the frame by the optical images of objects of the same brightness is maximum at the center of the field and gradually declines towards the edge of the image.

Fall of Illumination Towards the Edge of the Image

This fall of illumination is due to the influence of certain basic causes. Some of them are common to lenses of the most varied types and are not related to their design features.

The fall of illumination towards the edge of the field, due to the influence of factors of this group, obeys certain general regularities and can be established by calculation.

Since the distance from the lens to any point on the edge of the image is greater than the distance to the center of the field by a factor of $\frac{1}{\cos \theta}$, (where θ is the angle formed by the optical axis of the lens and the principal ray passing through this point), the illumination produced on the sensitive layer by the optical images of the photographed objects for any point of the image field will vary proportionally to cos θ. It must be taken into account here that the light rays passing through the lens fall at a certain angle on the marginal regions of the

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image field. In connection with this the illumination of the sensitive layer on the marginal areas, as a result of well known regularities, will vary likewise proportionally to the cosine of the angle of incidence of the rays on the illuminated surface, i.e. it will be proportional to $\cos^2\theta$.

Since the brightness of the light flux passing through the lens for points located at one side of the optical axis, i.e. for inclined beams, will be less than the brightness of the direct ray, likewise by a factor of $\cos\theta$, the illumination of areas of the optical image remote from the center of the field, by virtue of the influence of the above factors, will be less, by a factor of $\frac{1}{\cos^4\theta}$, than the illumination of the center of the field.

The reduction in the illumination of the boundary regions is very small when the image angles are small and has no substantial effect on the quality of the photographic image. When short-focus lenses with large image angles are used, the decrease in illumination becomes appreciably more. The quantity of illumination received by the sensitive layer at the edges of the image will be smaller than at the center of the field. The result of this will be a reduction in negative density on the marginal areas, which is particularly marked in cases of underexposure. This fact should be taken into account in the frame and setting the illumination of the photographed objects in cases when their images are located at the edges of the field.

The reduction in the illumination of the marginal areas of the optical image is particularly marked when motion picture lenses of short focal length are used. The illumination of the boundary areas for lenses of focal length from 5.0 to 10.0 cm, owing to the above enumerated factors, will amount to about 0.85–0.96 of the illumination of the center of the field, taken as unity. When short-focus lenses are used, the illumination at the edges of the frame amount to about 0.72 of the illumination of the center of the image field for a lens of 3.5 cm focal length, and for a lens with a focal length of 2.5 cm, to only 0.54 of that illumination

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(Table 6).

Table 6

Fall of Illumination of Marginal Areas of the Optical Image in Miniature Cameras

Focal length of lens in mm	Image angle along diagonal of photograph, (in degrees)	Illumination of the boundary areas of the image (the illumination at the center of the field is taken as 1.00)
28	75.5	0.39
35	63.5	0.55
50	47	0.74
85	28.5	0.91
135	18	0.95

In using miniature cameras, owing to the same factors, the illumination of the boundary areas of the optical image when interchangable lenses of various focal length are used, varies to an even greater extent.

In addition to the factors considered above, the influence of the vignetting effect, which is very closely related to the design features of the lens itself, has a very great effect on the fall of illumination in the marginal areas. The vignetting of the image is the result of the limiting of the light beam passing through the lens by the lens mounting. Vignetting is particularly great in operating at full stop, or with a shutter only slightly stopped down.

In connection with this, the actual fall of illumination towards the edge of the image is notably increased. When the lens is stopped down, the vignetting is decreased, and when the size of the effective aperture is considerably reduced, it becomes almost unnoticable. In these cases the differences in the illumination of the boundary areas of the optical image and the center of the field are due mainly to the influence of the above enumerated factors alone.

Fig.23 gives graphs of the distribution of the illumination of the optical image for a few Soviet motion-picture lenses (from the data of the lens testing

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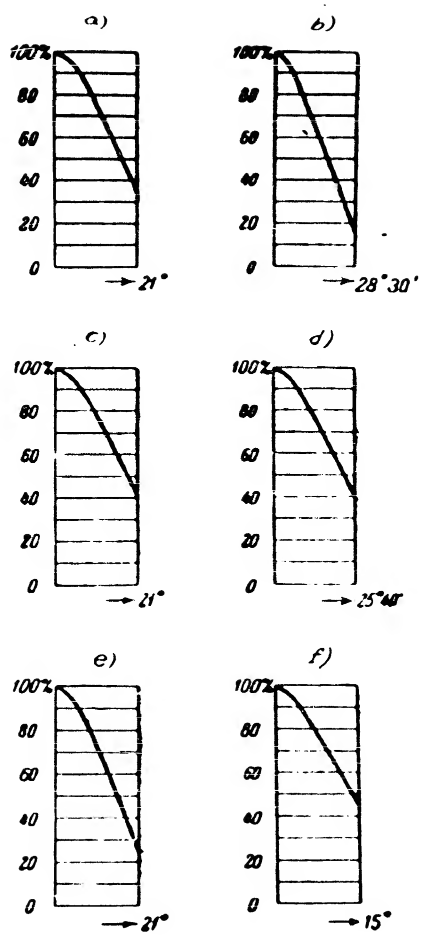

Fig.23. Graphs of the Fall in Illumination of the Optical Image Towards the Edge of the Frame for a Few Motion-Picture Lenses

a) Ro 56-1; f = 35 mm; b) Uran 21; f = 27 mm; c) Ro 57-1; f = 35 mm; d) Ro 13-1; f = 28 mm; e) Helios 33; f = 35 mm; f) Ro 3-3; f = 50 mm

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laboratory of the Mosfilm motion picture studio). It will be seen from these curves that the illumination of the marginal portions of the frame for most of the short focus lenses tested at a relative aperture of 1:2 does not exceed 25–40% of the illumination of the central areas of the image field.

Variation of Illumination of Sensitive Layer with Increasing Scale of the Image

The illumination of the sensitive layer is related in the closest way with the scale of the image of the photographed object. When the distance between the object and the camera is varied, the value of the relative aperture of the lens likewise varies, and consequently also the illumination of the optical image. These variations of the lens speed, which determine the variations in the illumination of the sensitive layer, must be taken fully into account in determining the exposure time and conditions.

In those cases where the distance from the camera to the object photographed is 15–20 focal-lengths of the lens used, these variations of the lens speed are very small and may be omitted from consideration in the practice of determining the exposure. With a considerable increase in the size of the image, determining the ratio of the linear dimensions of the image in the negative to the corresponding linear dimensions of the objects photographed, the influence of this factor rapidly increases.

Thus in taking a portrait, occupying in height the entire area of the frame (size of the object 48–50 cm in height, dimensions of the standard motion picture frame 16 x 22 mm), the scale of the image will be about 1/30.

In the case, however, of a picture with a very large detail, for example, the eye, likewise occupying the entire height of the frame (size of the object 30–32 mm in height) the scale of the image will be about $\frac{1}{2}$.

If the exposure time in taking an infinitely distant object is taken as unity, then in the first of these cases, the exposure time under the same illumination conditions, is found to be the extremely small value of 1.07, while in the second

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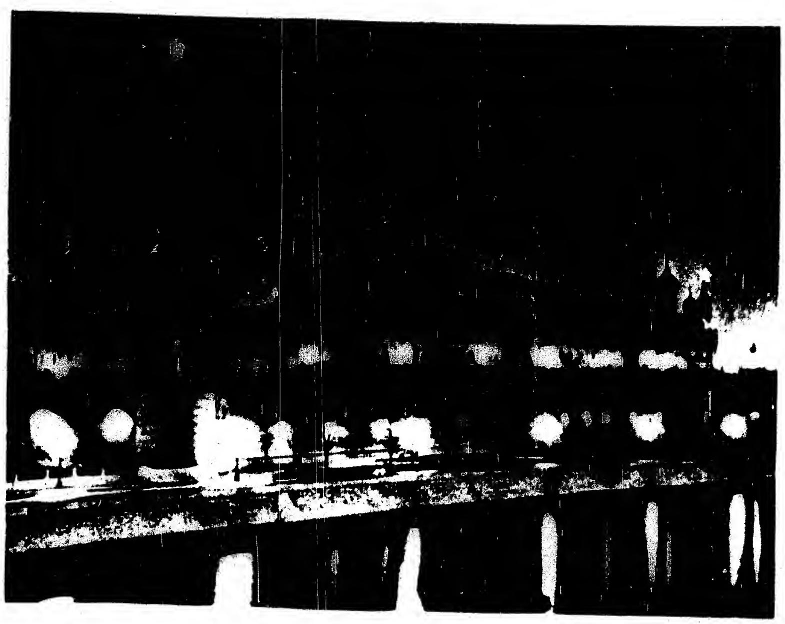

Fig.25. Brightness Range of Object Photographed Under These Conditions of Illumination is Very Great, and is Equal to About 400:1

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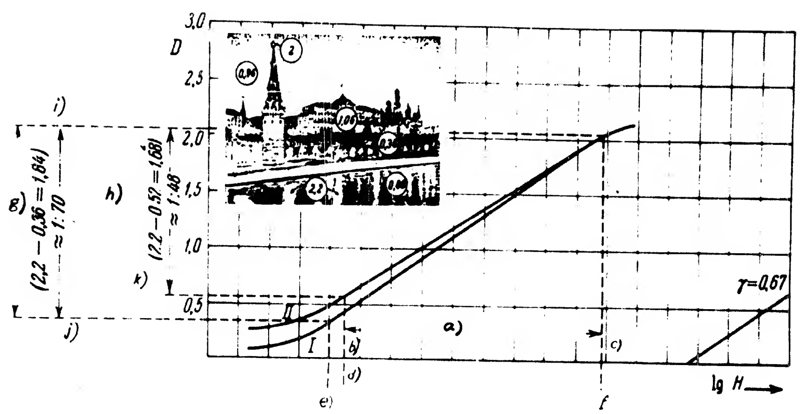

Fig.26. Influence of Light Scattering in the Lens and Camera on the Reduction of Contrast in the Image of the Photographed Objects Shown in Fig.25

a) Brightness range of object ≈ 400:1 ; b) B_{min}; c) B_{max}; d) $H_{min_{II}} = (H_{min} + H_{scatt})$ e) $H_{min_I} = B_{min} t$; f) $H_{max} = B_{max} t$; g) $D_{max} - D_{min}$; h) Range of density of negative: $D_{max} - D_{min_2}$; i) $D_{max} = 2.2$; j) $D_{min} = 0.36$; k) $D_{min_2} = 0.52$

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case it will be equal to 2.25.

The practical value of such a correction must not by any means be underestimated.

The value of the necessary exposure correction may be easily determined by calculation. Let us take the exposure time for ordinary cases of a picture with a small scale enlargement as unity. In this case, under unchanged conditions of illumination, the value of the exposure correction necessary when the scale of the image is increased, may be determined by the formula $(1 + 1/m)^2$, where $1/m$ is the scale of the image of the objects photographed.

As an example of the use of this formula in calculating the exposure, let us consider the case of a photograph of an object whose image scale on the negative is equal to 1.5. The size of the image in this case will be 1.5 times as great as the size of the object. The necessary exposure time in this case will be equal to $(1 + 1.5)^2 = 2.5^2 = 6.25$ and will be 6.25 times as great as the exposure for photographing the same objects at small image scales.

The necessary exposure corrections may be easily determined likewise with the aid of the nomogram given in Fig.24.

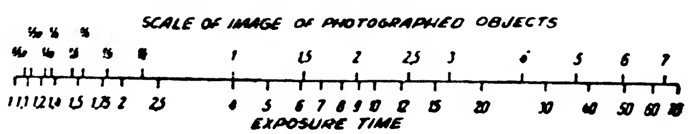

Fig.24. Nomogram for Determination of the Exposure Time When the Scale of the Image of the Photographed Objects Increases

Scattering of Light in the System Lens: Camera

On considering the question of the illumination of the sensitive layer and its influence on the time and conditions of exposure, we took into account only the basic relations existing between the brightness of the objects photographed and the illumination produced on the sensitive layer by its optical image. For a more exact

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estimate of the illumination of isolated areas of the optical image, and in particular, for the reproduction of the contrasts of the objects photographed, it is necessary to take account likewise of the scattering of light in the system lens-camera and its influence on the quality of the photographic image.

The illumination of each individual area of the sensitive layer in the camera is made up of the illumination produced on the layer by the optical images of the photographed objects, and a certain additional illumination produced by the light rays scattered in the lens and the camera.

Scattering of Light and Image Contrast

The sources of the scattered light in the camera are the reflection and scattering of the light rays in the optical system, and their multiple reflection inside the camera and in the mountings of the lens. When an uncoated optical system is used in the lens and camera, about [illegible] to 10% of the total quantity of light is scattered. Without taking part in the formation of the optical image, this scattered light forms, on the sensitive layer, a certain additional general illumination, which is superimposed on all the regions of the image. Without markedly affecting the increase in the illumination of the light areas, this additional light strongly increases the illumination of the shadowy, low-illumination areas of the sensitive layer, and thereby substantially reduces the contrast and the color characteristics of the image. In connection with this, the influence of the scattering of light becomes particularly marked when dark and weakly illuminated surfaces are present in the frame, together with a considerable brightness interval of the photographed object. The inclusion, in the frame, alongside of areas of low brightness, of objects of very great brightness, for example of open light sources, bright flashes, etc, exerts a particularly great influence on the quantity of scattered light, and, consequently, on the reduction of the image contrast.

As the design of lenses become more complex, i.e. with increasing number of air-glass surfaces of separation, the quantity of light diffused in the lens

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increases rapidly. On the average, in four-element anastigmats, with eight air-glass surfaces, the additional illumination of the sensitive layer due to scattered light not participating directly in the formation of the optical image reaches 6% of the mean illumination of the layer. When three-element lenses, having 6 air-glass surfaces, are used, about 4-5% of the total quantity of light forming the optical image is scattered.

In connection with this, the minimum illumination of the corresponding areas of the sensitive layer due to the optical images of the photographed objects whose brightness is very low, cannot fall below 5-10% of the mean illumination of the optical image when uncoated lenses are used.

The coating of the optical system of the camera cuts almost in half the quantity of scattered light and substantially increases the contrast-forming power of the lens. Studies made at the laboratory of photographic technique of the NIIFI, have shown that out of the total quantity of light scattered in the optical system and the camera when uncoated lenses are used, 65 to 75% is the share of the lens itself, while with a coated optical system, only 25-35% is such share. Thus, even when coated lenses are used, the rays of light that are scattered owing to multiple reflections from the elements and mountings of the lens, the sensitive layer and the camera details, are added on all parts of the optical image, and have a marked effect on its contrast.

The Coefficient of Contrast Loss

The reduction in the image contrasts may be characterized by the value of the coefficient of contrast loss, which represents the ratio of the interval of illumination of the optical image to the interval of brightness of the object. The value of the coefficient of contrast loss in the system lens-camera will substantially vary with varying character and contrast of the photographed objects. Studies have shown that for different lenses and cameras, the value of the coefficient of contrast loss in the optical image varies over a relatively wide range and reaches

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values from 1.15 to 9.5.

In photographs of high-contrast objects, the interval of illumination of the image, even when a coated optical system is used, may fall by comparison with the interval of brightness of an object by a factor of two or three or even more. Thus the reduction in contrast of the photographic image, defined by the properties of the negative material and the conditions of development, are supplemented and intensified by the influence of light scattering.

This fact, in photographing subjects with a wide interval of brightness, markedly increases the allowable errors in determination of the exposure time and becomes of substantial importance from the point of view of exposure measurement. Let us consider a specific example. The interval of brightness of the photographed objects shown in Fig.25 is very great, and is equal to approximately 400:1. If the scattering of light in the lens and camera were completely absent, the illumination of the corresponding areas of the layer could be determined on the basis of the known relations between the brightness of the photographed objects and the illumination of the sensitive layer produced by their optical images. In connection with the fact that the negative of this photograph is developed to a · less than unity, the brightness interval of the object taken by us is reproduced in the negative with a certain compression of contrast (Fig.26). The interval of densities of the blackening of the negative, corresponding to the minimum and maximum brightnesses of the object, without allowing for the scattering of light, would in this case determine the difference $D_{max} = 2.2$ and $D_{min} = 0.36$ and would be equal to 70:1.

But in reality, owing to the scattering of light in the lens and camera onto all regions of the layer, there will be a certain additional general illumination E_{scat} will be imposed. Without increasing perceptibly the illumination of the light areas, this scattered additional light will somewhat increase the illumination produced on the layer by the shade areas of the optical image. As a result, the quantity of illumination received by the layer on these areas increases to

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$E_{min} + E_{scat} \cdot t$, and the densities of blackening to the negatives corresponding to a minimum bright element of the object photographed, will increase from $D_{min} = 0.36$ to the density $D_{min} = 0.52$. Allowing for the quanity of illumination $H_{min_{II}}$, received at the given exposure time t by the individual areas of the sensitive layer, we construct the characteristic curve II (Fig.26). As will be seen from the figure, the form of this curve varies particularly strongly in its lower portion, i.e. on the section of underexposure, where the increase of illumination of the layer which is the consequence of the scattering of the light is particularly marked. Since the density $D_{min_2} = 0.52$ is greater than the density $D_{min} = 0.36$, the contrasts of the objects in the negative will be additionally lowered, and the interval of density of blackening of the negative will be equal only to 48:1. The contrast in the negative in this case will be reduced by a factor of 8.

In photographs characterized by a more uniform distribution of brightness and by lesser contrasts, using the same negative materials, lens and camera, the influence of light scattering on the reduction of image constrast is found to be considerably smaller (Fig.27).

Fig.28 gives data on the brightness of the individual elements of a photographed object measured in the directions of the camera. The brightness of the darkest intervals between the columns is equal to 900 apostilbs, and that of the lightest (the light globes of white milky glass) 34,200 apostilbs. The brightness range of this object is about 40:1 (Fig.27). As in the preceding example, the negative was developed to $\gamma = 0.67$. As a result of the compression of contrast of the negative image and the influence of the light scattering, both connected with this, the interval of densities of blackening in the negative, as shown in Fig.29, are found to be equal to 1:15, and will be lower by a factor of about 2.6 than the interval of brightness of the photographed object.

Allowing for this circumstance in practical work, it is necessary to bear in mind the fact that this lowering of contrast in the negative image will be

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Fig.27. At the Entrance to the New Building of Moscow University (Photographed by Yu.Gantman). The Brightness Range of the Photographed Object is About 40:1

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Fig.28. Distribution of Areas of Optical Densities on the Photograph (cf. Fig.27)

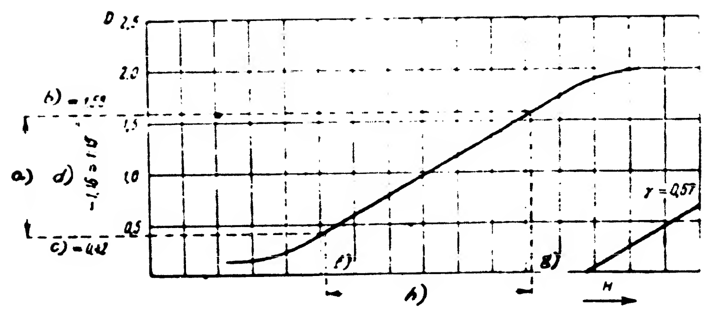

Fig.29. The Curve Shows that as a Result of the Development of the Negative of the Photograph (cf. Fig.27) to $\gamma = 0.67$, the Interval of Negative Densities is Reduced to 1:15

a) Interval of optical densities of negative; b) D_{max} ; c) D_{min} ; d) $D_{max} - D_{min}$; f) B_{min}; g) B_{max} ; h) Brightness range of object 1:40

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compensated to some extent during the printing of the positives, by the higher contrast of the positive materials.

By studying the influence of these basic factors we will be able completely to express the relation between the brightness of the photographed object and the illuminations corresponding to these areas of the sensitive layer.

Allowing for the influence of these factors, the illumination produced on the sensitive layer by the optical images of these or those elements of the photographed object, whose brightness is expressed in apostilbs, may be determined from the equation:

$$E_{im} = B_{ob} \frac{f^2}{4v^2 n^2} \cos^4 \theta \cdot \tau \cdot K_{vign} \cdot K_{scat}$$

where E_{im} is the illumination of the optical image of the element of the photographed object in lux; B_{ob} = brightness of element of photographed object measured in the direction of the camera in apostilbs; f = focal length of the lens; $n = f/d$ = the s top number, i.e. the reciprocal of the relative aperture of the lens; v = the distance from the rear nodal point of the lens to the plane of the image in the camera; θ = angle between optical axis of the lens and the direction to the given point of the image; τ = coefficient of transmission of the lens; K_{vign} = coefficient of transmission of the lens for points lying outside the axis, due to the influence of the vignetting of the image; K_{scat} = scattering of light in the system lens-camera which, for a specific object, also defines the conditions of exposure.

By combining the influence of the various parts of the above enumerated factors, the equation may be represented in the following simple form:

$$E_{im} = B_{ob} \frac{f^2}{4v^2 n^2} \cdot K$$

where K = the coefficient of light loss in the optical system.

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INFLUENCE OF PHOTOSENSITIVITY AND COLOR SENSITIVITY OF NEGATIVE MATERIALS ON THE TIME AND CONDITIONS OF EXPOSURE

The photosensitivity of negative materials is one of the most important practical characteristics. In using photographic plates or films having different sensitivity, the time of exposure under one and the same conditions of photography must be inversely proportional to their sensitivity. Thus, the use of negative materials of higher sensitivity makes it possible successfully to take pictures under less favorable illumination conditions, and with a shorter exposure time than when less sensitive plates and films are used.

The GOST System

The sensitometric system GOST, developed by Soviet scientists, expresses the photosensitivity of photographic materials by a quantity that is the reciprocal of the value of the exposure expressed in lux-seconds which produces on the photographic layer a blackening with an optical density of 0.2 over the density of the fog. The photosensitivity of photographic materials is thus determined by the formula $S = \frac{1}{H_{D_0 + 0.2}}$, where S is the photosensitivity expressed in GOST units, and H = values of the exposure corresponding to the density $D_0 + 0.2$.

The development of the test plates or films must be conducted in a definite developer to the contrast coefficient recommended by GOST for the given negative material.

The fundamental advantage of the system of the GOST sensitometric system is the approximation of the test conditions and the expression of the properties of photographic materials, to the conditions of their practical utilization in photography. The relative practical sensitivity of various negative materials when expressed by this system of sensitometric measurements is found to be directly proportional to the number of GOST units.

The photosensitivity of photographic materials in GOST units is established in

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the following manner. On the characteristic curve constructed on the standard sensitometric blank, the point corresponding for the given test material to the density 0.2 above the fog density (point A on Fig.30) is marked. The perpendicular dropped from this point to the graph of the scale of photosensitivity values in the lower part of the graph shows at the point of intersection with this scale of the photos , at its point of intersection with this scale, the photosensitivity of the test material expressed in GOST units. For example, the sensitivity of negative motion picture film the characteristic curve of which is given in our drawing, for its development to the recommended value $\gamma = 0.65$ is found to be equal to about 50 GOST units.

In connection with the fact that the sensitivity of certain photomaterials and their designation on the calculators of certain photoelectric exposure meters is expressed not in GOST units, but in degrees of other sensitometric systems, it is sometimes necessary, in exposure measurement calculations, to recalculate, and compare among themselves, the values of the photosensitivity determined by different methods.

In connection with the fundamental differences in the criteria of sensitivity on which this or that sensitometric system is based, there can be no constant and precise coefficient of conversion of the degrees of one sensitometric system into the degrees of another. This is explained by the approximate character and the inexactness of the comparative data on the sensitivity of these or those negative materials, expressed in units or degrees of the various sensitometric systems.

Comparative tables may have a certain practical significance only in those cases where they have been compiled on the basis of numerous studies taking full account of the peculiarities of use and of laboratory processing of the plates and films. But even in these cases we must still take into account the possibility of very substantial differences between the value of the actual sensitivity of one negative material or another determined under the specific practical conditions of

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photography and processing, and the value of this sensitivity determined from comparative tables.

On page 68 the comparative Table 7 is given, showing the values of the photosensitivity of negative materials expressed in units of various sensitometric systems. The last column of this table contains the data on the relative photosensitivity of various materials.

The questions of the photosensitivity of negative materials cannot be consider-

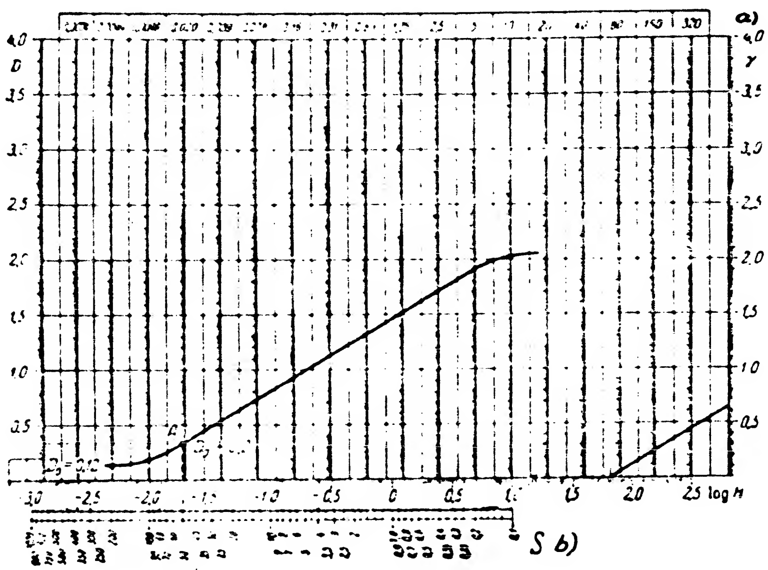

Fig.30. Determination of the Photosensitivity by the GOST Sensitometric System

a) H, lux-sec; b) S (GOST units)

ed without a comprehensive consideration of their spectral sensitivity. This is connected with the fact that the sensitivity of the emulsion in films under various conditions of photography is found to be inconstant and varies markedly under variation of the spectral composition of the light illuminating the photographed objects.

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The differences between the photosensitivity of different negative materials therefore determine not only the character of the color reproduction, but also take on the most substantial significance from the point of view of exposure measurement as well.

Table 7

Comparative Table of Relative Values of the Photosensitivity of Negative Materials in Different Sensitimetric Systems

GOST	Hurter and Driffield (H and D)	DIN	Weston	General Electric	Relative Photosensitivity
6	150	10/10	5	8	0.16
8	200	11/10	6	10	0.2
11	250	12/10	8	12	0.25
16	350	13/10	10	16	0.33
20	400	14/10	12	20	0.4
22	500	15/10	16	24	0.5
25	600	16/10	20	32	0.64
32	700	17/10	24	40	0.8
45	900	18/10	32	48	1.0
50	1,250	19/10	40	64	1.3
65	1,400	20/10	50	80	1.6
90	2,000	21/10	64	100	2.0
100	2,500	22/10	80	125	2.5
130	3,000	23/10	100	150	3.2
180	4,000	24/10	125	200	4.0
200	5,000	25/10	160	250	5.0
250	6,000	26/10	200	300	6.0
300	8,000	27/10	250	400	8.0
400	10,000	28/10	320	500	12.0

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In connection with this, in determining the time and conditions of exposure we must invariably take into consideration the variations in photosensitivity of the negative materials due to the variations of the spectral composition of the illumination. The value of the exposure corrections necessary under these or those conditions of illumination, and compensating these variations of sensitivity, may be easily established by trial photographs.

In determining the time and conditions of exposure by means of photoelectric exposure meters, in connection with the variation of the spectral composition of natural illumination and of the spectral characteristics of artificial light sources, the necessary corrections, determined experimentally, must likewise be applied to the instrument readings. In photographs taken, for example, on panchromatic negative materials under the light of incandescent lamps, the value of this correction may reach 30-40%. In practice we can allow for these variations by lowering the index of sensitivity of negative materials set on the calculator of the exposure meter, to 60-70% of the photosensitivity determined for the case of a photograph under natural illumination or illumination by high-intensity arc lamps.

The Photosensitivity of Multi-Layer Color Negative Materials

In connection with the small photographic density of multi-layer negative films, color photography demands far higher accuracy in the determination of the exposure and exposure conditions photography with ordinary black-white negative materials. One of the basic conditions of the accuracy of exposure-measurement calculations performed by the aid of tables, or of photoelectric exponometers, is the calculation, to the utmost possible degree of accuracy, of the photosensitivity of the negative materials employed.

But the technique of sensitometric estimates and of the exact expression of the sensitivity of multi-layered films at the present time is still inadequately developed. For this reason, the conditions of exposure assuring the possibility of a correct and undistorted reproduction of the color of the object photographed may

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be taken as a certain criterion of the sensitivity for the given negative color film. In comparing the sensitivity of the color film to the sensitivity of those white-and-black negative materials that, under the same conditions of illumination and exposure, give high-grade results, that sensitivity may, with accuracy sufficient for practical purposes, be expressed arbitrarily in the usual units of sensitivity.

In most cases, the sensitivity of colored negative films of type DS, intended for photographs under natural illumination, or under the light of high-intensity arc lamps varies for DS-1 film, from 400 to 600° H and D, and for DS-2 film, from 800 to 1400° H and D, which amounts roughly to from 32 to 60 GOST units.

The photosensitivity of negative color films based on the utilization of artificial light, (incandescent bulbs), reaches, for films of the new LN-2 type, a value from 700 to 1250° H and D, roughly from 30 to 50 GOST units.

Development of Negative Materials and its Influence on the Exposure Conditions

One of the most important stages in the formation of the photographic image is the development of the latent image which arises as a result of exposure. A variation in the state of the developer or the conditions of development has a very distinct influence on the basic exponometric characteristics of the negative materials used, on their photosensitivity, their contrast, and their photographic width.

In this connection, in practical photographic work, on calculating the times and conditions of exposure, it is necessary to take account of the peculiarities of the development and of its influence on the photosensitivity of the negative material used.

The studies made at the All Union Research Institute for motion picture photography by V.I.Sheberstov, have confirmed the view that fine grain developers with borax, in comparison with the ordinary rapid acting metol-hydroquinone developers with sodium carbonate, somewhat increase the photosensitivity of negative materials. The fine grain developers with paraphenylenediamine, and a few others, strongly

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lower the photosensitivity of the material and therefore require a marked increase of the exposure time.

The work of S.M.Antonov, K.I.Markhilevich and others have also shown that developers of this type and certain other fine-grain developers somewhat increase the photographic width of the negative material as well. Table 8 gives data on the influence of certain of the most widely used fine-grain developers on the photosensitivity of negative materials as compared with the usual metol-hydroquinone developers.

In determining the time and condition of exposure by the aid of exposure meters, these influences may be estimated from the results of test exposures by setting up on the calculator the corresponding variable values of the sensitivity of the plates and films.

Table 8

Effect of Certain Fine Grain Developers on the Photosensitivity of Negative Materials by Comparison with the Usual Metol-Hydroquinone Developers

Type of developer	Typical formula for developer	Effect on photosensitivity of negative material
Fine-grain metol developer NIKFI formula	Metol 5 g Sodium sulfite, anhydrous 75 g Borax, crystallized 12 g Boric Acid 4 g Water to 1000 ml	Marked increase of photosensitivity, by as much as 1.5 to 2 times
	Mean time of development 12-20 min at 20°C	
Type D-76 developer	Metol 2 g Hydroquinone 5 g Sodium sulfite, anhydrous 100 g Borax, crystallized 2 g Water to 1000 ml	Marked increase of photosensitivity
	Mean time of development 15-20 min at 20°C	

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(table continued)

Type of developer	Typical formula for developer	Effect on photosensitivity of negative material
"Final" developer	Metol 3.5 g Hydroquinone 3.5 g Sodium sulfite, anhydrous 50 Sodium citrate 10 g Borax, crystallized 6 g Potassium bromide 0.4 g Sodium hexametaphosphate 0.12g Water to 1000 ml	Some increase in photosensitivity
	Mean development time 10-15 min at 18°C	
Paraphenylenediamine fine-grain developer	Sodium sulfite, anydrate 90 g Glycine 8 g Paraphenylenediamine 10 g Water to 1000 ml	Paraphenylenediamine developers lower the photosensitivity of negative materials and therefore require an exposure 1.5 to 2 times as long
	Mean exposure time 15-20 min at 18-20°C	
"Atomal" developer	Beta-otyethylorthoaminophenol sulfate 6 g Sodium sulfite, anhydrate 100 g Sodium carbonate, anhydrate 10 g Potassium bromide 0.5 g Sodium hexametaphosphate 1 g Water to 1000 ml	Somewhat lowers photosensitivity, and, according to type of negative material, requires 1.5 to 2 times longer exposure
	Development time 8 to 18 min at 18°C (according to type of negative material)	
Developer with sodium thiosulfate	Metol 2.5 g Sodium sulfite, anhydrate 25 g Hydroquinone 1.25 g Sodium bicarbonate 15 g Sodium thiosulfate, crystallized 0.5 g Water to 1000 ml	Strongly reduces photosensitivity and requires 2 to 3 times as long exposures
	Mean development time 20-25 min at 18-20°C	

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DETERMINATION OF EXPOSURE TIME AND CONDITIONS BY THE METHOD OF TEST EXPOSURES

The determination of the time and conditions of exposure by the method of test exposures is the oldest and simplest method of finding the accurate exposure.

The simplicity and reliability of this method, in spite of the fact that it involves a considerable loss of time and cannot be carried out without certain conditions and equipment, have made it generally used.

In practice, the accurate exposure time is usually found as a result not of a single test exposure but of at least two, and sometimes more. With fairly large deviation in their exposures we thus obtain a certain exposure range giving the necessary basis for a judgement as to the exposure time and conditions and of the photograph corresponding to the particular problem.

Determination of the Conditions of Exposure by the Aid of the Exponogram

In motion picture practice, the method of exposure by the aid of an exponogram is used with relative frequency. This method assures not only the determination of the necessary amount of illumination, but also makes it possible to select the optimum conditions of exposure on the basis of an analysis of the negative obtained. In practice, this method reduces down to obtaining an exponogram, or exponometric wedge, i.e. a series of precisely measured exposures, and the development of the negative under conditions most closely approaching the conditions of its processing in actual production. In cameras provided with a mechanism that automatically closes or opens the obturator, it is expedient to utilize such an automatic obturator for the precise setting of the exposures obtained as a result of varying the slit, i.e. the angle of opening of the obturator. Since when taking such an exponogram, the brightness of the object photographed and the value of the relative aperture both remain constant, the quantity of illumination received by one frame or another is completely determined by the time of its exposure, i.e. by the angle

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of opening of the obturator.

The lens must be stopped down in this case in such a way that the first frames of the exponogram, corresponding to the maximum angle of opening of the obturator, shall be somewhat overexposed.

Since, when using the automatic device, the angle of opening of the obturator during the time of exposure is varied continuously and uniformly, it is easy to determine, for each given frame of the exponogram, the exact value of the exposure corresponding to it. To determine the time during which some specific frame was actually exposed, it is necessary to learn the number of this frame, starting from the beginning of the stopping down, and then, by the following formula, to calculate the conditions of its exposure:

$$t_n = \frac{\gamma_{max} \cdot K_n}{360 \cdot v \cdot O_{cl}}$$

where t_n = time of exposure of the frame; γ - maximum angle of opening of the obturator at the beginning of the exponogram; K_n the number of the frame, counted from the beginning of the stop-down; v - frequency of exposure (number of frames per second); O_{cl} = length of automatic obturator closure, expressing the number of darkening frames.

As an example of the practical use of this formula, let us consider the following case of the taking of an exponogram. A camera whose automatic shutter closure lasted for 64 frames was used. The maximum angle of opening of the obturator, i.e. γ_{max} = 175°. The number of frames per second v = 24. The negative of the best quality, and consequently also the optimum exposure conditions under these conditions, correspond roughly to the 28th frame of the exponogram, counting from the beginning to the obturator closing, i.e. K_n = 28. In this case the exposure time of this particular frame, i.e. t_{28}, is equal to 175 x 28/360 x 24x64 = 1/112 sec, and will be 1/2.28 the exposure with fully opened obturator. The results of this experiment enable us exactly to find the obturator opening and stop that are

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necessary under these conditions.

When manual automatic motion picture cameras with a constant angle of obturator opening are used, the test exposures are usually made by varying the effective aperture of the lens.

USE OF TABLES AND CALCULATORS

The accumulated experience of many years has led to the appearance of tables and graphs helping to determine the correct exposure time under given conditions. In most cases their calculation is based on the exposure time found experimentally for various objects enumerated in the tables, which are photographed under definite conditions.

In these tables the exposure or correction factors corresponding to specific conditions of photography, and defining the influence on the exposure time of the following factors to be taken into account are calculated:

a) character of objects photographed and its exposure indexes;

b) geographic position of photograph;

c) time of photograph, month, time of day;

d) state of the sky;

e) photosensitivity of the negative material used;

f) relative aperture of lens;

g) number of color filter used.

The fact that the illumination produced on the photographed objects by the light of the cloudless sky and the sun for a given time and geographic point under the same atmosphere conditions is practically constant was very important in working out such tables.

On this basis, tables were worked out in which the values of the illumination produced by daylight for each day and hour is given with respect to the given conditions.

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In some tables, to determine the exposure time corresponding to these or those conditions of photography, it is necessary to multiply a number of quantities determined by the influence of various factors. In most tables these quantities are expressed logarithmically, and in these cases multiplication is replaced by the easier operation of addition, after which the required exposure time is found in the corresponding columns from the sum of the logarithms.

In connection with the fact that these calculations are in practice rather burdensome and take no small amount of time, devices built on the principle of the slide rule have been constructed, and also in the form of various movable circular scales matched with the scales of mixed circles. Such devices include the many calculators which are produced today for the exposure time and conditions. In calculating exposures on these instruments, the principal exponometric factors are taken into account.

The fundamental fault of exposure tables and calculators of this type is the abundance of factors that are hard to classify, and the replacement of constants for a given photograph by values with variable factors which cannot be exactly determined.

In spite of the apparent exactness of these tables and calculators, and in spite of the fact that they have been compiled on the basis of numerous observations, the accuracy and reliability of their results must not be overestimated. It must also be borne in mind that the results of calculation can never be more accurate than the initial data on which they are based. In the case under consideration, many of these data (classification of the photographed object, state of the sky, conditions of illumination, etc) are determined arbitrarily, by eye. The conclusion may be drawn from the above that the primary shortcoming of this method of determining the time and condition of exposure is the subjectivity and indeterminacy of the evaluation of a number of the most important exponometric factors, while many circumstances of the photograph that are important, and sometimes even

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decisive, cannot be taken into account with necessary exactness.

OBJECTIVE EXPOSURE MEASUREMENT

The Significance of Objective Methods of Determining the Time and Conditions of Exposure

The practice of determining the time and conditions of exposure from tables, or by the aid of various photometers, was unable to assure the necessary quality and constancy of photographic results. The efforts to construct instruments that would make it possible to provide objective, quantitative estimates of the features of the photographed objects and of the illumination were therefore entirely justified. Throughout the whole history of photography, inventive and designing thought was particularily active in this direction. Many devices and instruments of every possible kind were proposed to assist in the practical solution of this important problem.

The appearance in 1932 of the first models of exposure meters of a fundamentally new type, based on the photoelectric principle, helped to develop the recent methods of exposure measurement and to introduce them into motion picture practice. The widespread use of photoelectric devices for exposure measurement was substantially facilitated by the fact that the use of photocells to measure radiant energy began with the very first steps of the study of the phenomenon of the photo-effect by the Russian scientist, Professor Stoletov, and the technique of the corresponding measurements had already been worked out in sufficient detail by the time of their introduction into the practice of motion-picture and still photography.

The possibility of making measurements of the brightness or illumination of the photographed object by the aid of precision instruments under any conditions, and of obtaining the necessary quantitative characteristics of these quantities, considerably facilitated the solution of the problem of correct exposure.

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POOR ORIGINAL

In the practice of photography, it first became possible, as a result of direct measurements at the site, to solve the equation $H = E_{layer} \cdot t$, where $E_{layer} = B_{ob} \cdot \frac{f^2}{4v^2n^2} \cdot K$ not empirically, but with an accuracy that was entirely adequate to assure the necessary quality of the results.

In the above equation, E_{layer} = illumination of sensitive layer produced by the corresponding area of the optical image; B_{ob} equals brightness of object photographed, measured in the direction of the camera; v equals distance from rear nodal point of the lens to the image plane in the camera; n = f/d equals the stop number, i.e. the reciprocal of the relative aperture of the lens; K equals coefficient of light loss in the optical system.

The exceptional advantages of photoelectric instruments, the objectivity of the measurements obtained by their aid, the considerable constancy of their total and spectral sensitivity, and the closeness of that spectral sensitivity to that of the eye, all assured these instruments of the widest introduction into all fields of photometric measurements.

In connection with the very small photographic width, and the limited color range of modern multi-layer films, the methods of objective exposure measurement have acquired particularly great significance in the practice of color photography.

Determination of Exposure Conditions by Means of Photoelectric Instruments

Fig.31 is a schematic diagram of photoelectric light-measuring instruments. These instruments consist primarily of a photocell with a selenium layer and a direct-current electrical measuring system connected with it, consisting of a needle magnetoelectric micrometer. The range and accuracy of the measurements made with them depend not only on the sensitivity of the photocell itself, but also on the sensitivity of the electric measuring device connected in the circuit.

In most instruments, depending on their function, the micrometer scales are calibrated in absolute units of illumination, or brightness.

Instruments with scales calibrated in arbitrary units are also used.

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In their simplest form, such instruments were designed to measure the illumination of the scene being photographed. The calculations of the exposure time and conditions based on the measurement of the illumination, without allowing for the peculiarities of the photographed object and for the conditions of the illumination of the important elements of its subject, led in many cases to serious mistakes in determining the exposure.

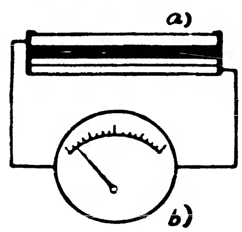

Fig.31. Schematic Diagram of Photoelectric Luxmeter-Light-Meter, designed to measure the illumination of the object photographed.

a) Sensitive surface of photocell

b) Micrometer

The design of instruments intended to measure the brightness of the photographed objects (the so-called brightness meters, Fig.32) repeat, on the whole, the basic scheme of the luxmeters, or light meters, designed to measure the illumination, and differ from them only in the presence of limiters of the angular field of the instrument, consisting of lattice diaphragms with cells of various forms, lattice diaphragms with lens raster, ordinary diaphragms, planoconvex lenses, etc.

Since most exposure meters, i.e. instruments specially designed for the determination of exposure and provided with a calculator, are based on the measurement of the brightness of the objects photographed, an indispensible condition for the satisfactory operation of an exposure-meter-brightness meter is a limitation of the angular field to prevent outside rays, not originating in the object being photographed, from acting on the sensitive surface of the photocell.

Thus the minimum requirement determining the degree of limitation of the angular field of the instrument is the equalization of this angle with the angular field of the lens used.

In this case as well, however, it is still impossible to measure the brightness

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of objects of small areas, but which are often of essential importance for a given subject, without bringing the exposure meter very close to the surface being measured. The exact measurement of the brightness of a certain area of the object photographed is thus replaced by the measurement merely of its mean integral brightness.

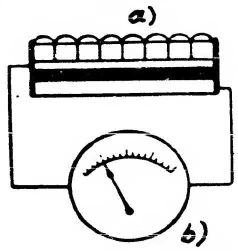

Fig.32. Basic Scheme of Photoelectric Brightness Meter designed to measure the brightness of the object photographed. a) Angular-field limiter (lattice diaphragm with lens roster; b) Micrometer

Even in measurements of the brightness of small areas of a texture surface, in spite of the fact that we distinctly distinguish its structure and the microflashes and shadows characterizing it, the results of such measurements likewise represent merely the estimate of a certain average brightness.

The deflection of the micrometer pointer are determined in this case not by the minimum or maximum brightness of the objects photographed, or by the brightness of parts of the frame important for the subject, but by a very indeterminate quantity of the mean brightness, which depend on the ratio of the areas occupied by details of various brightness in the object.

This fact may in many cases lead to substantial errors in determining the time and conditions of exposure.

We present the following cases from photographic practice as examples to illustrate this proposition.

In the first of these examples the object of the photograph is a brightly illuminating human figure occupying a relatively small part of the picture area and placed against a dark, weakly illuminated background. The differences between the brightness of the object and that of the background are very great. In the second case, the same brightly illuminated figure is placed against a bright,

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illuminated background.

In measuring the brightness of scenes being photographed, using an exposure meter, it is not only the rays reflected from the figure being taken that fall on the sensitive surface of the photocell, but also the light rays reflected from all other remaining elements of the subject having equal brightness. The pointer of the electric measuring device of the exposure meter will in this case indicate a certain total mean brightness of the object of photography as a whole.

In these cases, with the same brightness of the figure, the total quantity of luminous energy acting on the photocell of the exposure meter will be found to be different.

If this average total brightness of the object photographed is used as a base for the calculation of the necessary exposure conditions, then the exposure time will be, with respect to the main element of the subject, i.e. to the human figure, too high in the former case, and the negative for this principal area, important for the subject, will be overexposed. In the latter case, the difference of brightness between the object and the background will be small, and the exposure time determined from the readings of the exposure meter, will be correct.

In the former case it will be possible to avoid errors only if the measurements of the brightness of the corresponding elements of the object allow for the angular field of the instrument, in the immediate proximity of the measured surface. The exposure meter readings will be determined in this case by the actual brightness of each of the measured areas of the surface of the object, and the calculation of the exposure may be calculated in accordance with this brightness of the main subject elements of the image.

This fact completely justifies the demand for a considerable reduction in the angular field of brightness-exposure meters. But in spite of the obvious expedience, the possibility of satisfying this demand is limited by the sensitivity of the photocells and micrometers.

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With a considerable limitation of the angular field of the instrument, the quantity of light falling on the sensitive surface of the photocell decreases. This results in reduction of the sensitivity of the instrument as a whole, and a substantial increase in the value of the minimum brightness that can still be measured.

In most exposure meters used in motion picture production and in still photography, the angular field ranges from 50 to 70°. In some instruments with a rectangular sensitive photocell surface, the angular field in the vertical plane differs substantially from the angular field along the horizontal (Fig.33).

The [illegible] FP-4 exposure meter, developed by NIKFI and produced by the plant of the MKIP, has a relatively small angular field. In this instrument, which consists of a combined luxmeter and brightness meter, the angular field of the cap for measuring brightness is about 34° (Fig.34). In measuring low brightnesses, which is done without a cap, the angular field is about 100°.

Sensitivity of Photoelectric Exposure Meters

The sensitivity of photoelectric exposure-and-brightness meters varies from type to type. The minimum value of the accurately measurable brightness at angular fields of the order of 50–60°, is from 300 to 500 apostilbs for most instruments used by amateurs. The sensitivity of these exposure meters thus makes it possible to measure the brightness only for well illuminated objects. In order to characterize these quantities practically, it must be pointed out that these brightnesses correspond to the brightness of the human face under illumination of 1000–1500 lux, which is usual for motion-picture studio takes on black and white negative materials. In still photography, the level of illumination of the objects is in most cases considerably lower. In connection with this fact, the measurement of the brightness of individual areas, like that of the objects as a whole, of many existing models of exposure-brightness meters today, in the practice of white and black at the present time, in black-and-white motion picture photography in the studio,

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and in still photography with artificial sources of light, is becoming more and more difficult. This is explained by the fact that, with the introduction, into commercial work, of the latest types of negative films produced by the USSR motion-picture film industry, with their extraordinarily high sensitivity, the general level of illumination of the scene being photographed has sharply fallen.

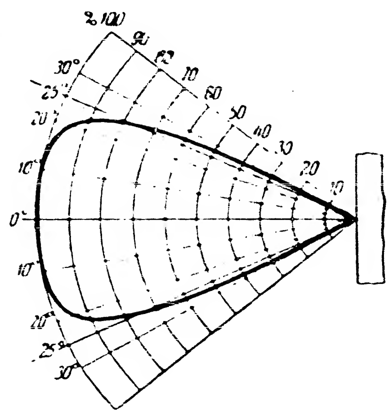

Fig.33. Curve Characterizing the Angular Fields of the EP-4 Exposure Meter, which is provided with a cap for measuring brightness.

In these cases, the measurement of the brightness of the individual areas of the frame, with which the motion picture operator and still photographer must deal when using high-sensitivity black-and-white negative materials, is often a task that is difficult to perform in actual practice. We may say that, when using modern high-sensitivity negative films to obtain a density of 0.8–0.9 for the face (at γ = 0.65–0.7) a brightness level of the object of 100–150 apostilbs is sufficient, while the minimum brightness that can be measured with most of the exposure-brightness meters now in use must be not less than 300–500 apostilbs.

Since the possibility of using an instrument to determine the conditions of exposure at low illuminations of the objects depends on the lower boundary of sensitivity, it follows that the efforts of designers have recently been directed towards a substantial increase in the sensitivity of the exposure meters. Thus, in the latest model of the USSR exposure meters EP-4, the lower boundary of the measurement range of low brightness has been reduced to 50–100 apostilbs, which considerably expands the possibility of using this instrument under the conditions of

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low illumination.

The sensitivity of various photoelectric exposure meters in the region of the minimum measurable brightnesses may be evaluated comparatively from the illumination of the photocell that results in a pointer deflection of some definite value, for example 1 mm.

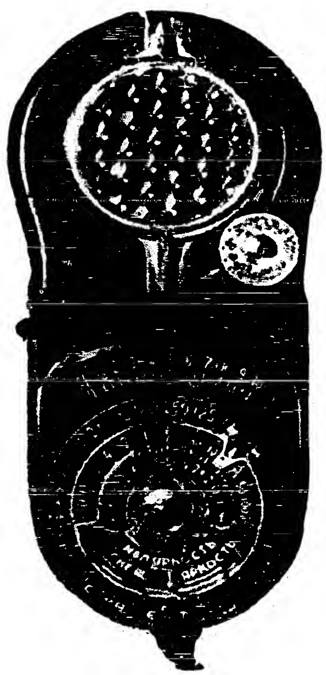

Fig.34. In the USSR EP-4 Exposure Meter, the Cap for Measuring the Brightness of the Objects Consists of an Optical Device Composed of a Multi-Lens Grid and a Honeycomb Lattice.

a) Illegible; b) Illumination; c) Brightness.

In this case, the comparative sensitivity of exposure meters may be calculated by the formula $S = d/E$, where S = relative sensitivity of the instrument for 1 mm of pointer deflection; d = deflection of micrometer pointer (in mm); E = illumination of sensitive surface of photocell, in lux, or brightness of the surface being measured (in apostilbs for mm of pointer deflection).

The values of the illumination of individual elements of the object may fluctuate over a very wide range, from a few tens of lux up to 100,000 lux and more. The brightness of the objects may vary even more widely. And yet the dimensions of the micrometer scale limit the range of measurements that can be made. In this connection photoelectric exposure meters with two or more measurement ranges are ordinarily used.

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Color Sensitivity

The successful use of various forms of photoelectric instruments in objective photometry may be considered to be assured only when brightnesses (or illuminations) with equal, or at least with very similar, spectral characteristics are being compared. In exposure measurements, alongside of the determination of the brightness level of the scene to be photographed, the correct evaluation of the measured brightness becomes particularly important with respect to the actinic power of the light reflected by the objects, and its action on the sensitive layer of the negative material used.

The data on brightness or illumination of the object obtained by the aid of the exposure meter provides no direct basis for the analysis of the light flux and the judgement of its spectral composition. In connection with this it is necessary to determine the extent to which the selenium photocells used in modern instruments meet the demands made on photographic exposure measurements. In the ideal case, the spectral sensitivity of such an exposure meter should coincide completely with the spectral sensitivity of the negative material determined after allowing for the spectral transmission by the optical system and color filters used. It is only when this condition is satisfied that the readings of an exposure meter can be utilized with sufficient confidence in the accuracy of the results.

If the spectral characteristics of the photocell do not coincide with those of the negative material, corrections of one kind or another must be applied to the calculations of exposure.

The value of these corrections is determined by the color sensitivity of the negative material, the character of the object photographed and the spectral composition of the illumination.

The spectral sensitivity of the photocells used in the practice of exposure measurement, is close to the spectral sensitivity of the average human eye. The

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curves of spectral sensitivity of even the best modern panchromatic negative materials, in spite of the substantial improvement in their quality, still differ from the curve of the spectral sensitivity of the eye.

From a comparison of the data on the values of the relative spectral sensitivity of the human eye and the selenium photocell it is clear that the relative sensitivity of the photocell in the region of the violet, blue, blue-green and orange-red zones of the spectrum considerably exceeds the value of the relative sensitivity of the eye (Table 9, Fig.35).

On comparing the spectral sensitivity of the photocell, of the average panchromatic negative material, and of the human eye, the conclusion may be drawn that photocells, in the distribution of their spectral sensitivity and their correspondence with the spectral sensitivity of panchromatic material, appreciably surpass the normal human eye.

Let us discuss this in greater detail. While the sensitivity of the eye for wavelength 420 millimicrons (violet) is equal to only 0.[illegible]% of its maximum sensitivity, the sensitivity of a selenium photocell reaches 56%. The relative mean sensitivity of panchromatic negative material for this wavelength is 70%.

For wavelength 460 millimicrons (blue), the relative sensitivity of the eye, the photocell and panchromatic negative material are 6, 68 and 87% respectively; at 520 millimicrons (green), 71.6, 87 and 30%, respectively; at 680 millimicrons (red), 1.7, 12 and 87 respectively.

From a comparison of these values the conclusion may be drawn that photocells with a selenium layer have a spectral sensitivity which on the whole assures the possibility of their successful use in exposure measurements.

The results of measurements made by their aid prove to be incomparably more accurate than the results of the most careful visual estimates of the illumination or brightness of photographed objects. The data on the time and conditions of exposure obtained on the basis of this measurements do not in practice differ

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Table 9

Relative Spectral Sensitivity of Receivers of Radiant Energy, (in percent)

Wavelength in millimicrons			Human eye	Selenium photocell (mean data)	Panchromatic negative material
Ultra-violet	Invisible rays	340	-	26	35
		360	-	35	44
		380	-	42	55
Violet		400	0.04	50	66
		420	0.4	56	77
		440	2.3	62	89
Blue		460	6.0	68	87
		480	[illegible]	[illegible]	[illegible]
Blue-green		500	32.3	81	31
Green		520	71.6	87	30
Yellow-green	Visible rays	540	95.4	94	32
Yellow		560	99.5	99	34
		580	87.0	99	33
Orange		600	63.1	95	32
		620	38.1	83	31
Red		640	17.5	61	26
		660	6.1	30	18
		680	1.7	12	8
		700	0.41	4	2
Dark red		720	-	-	-
		740	-	-	-
		760	-	-	-
Infra-red	Invisible rays	780	-	-	-

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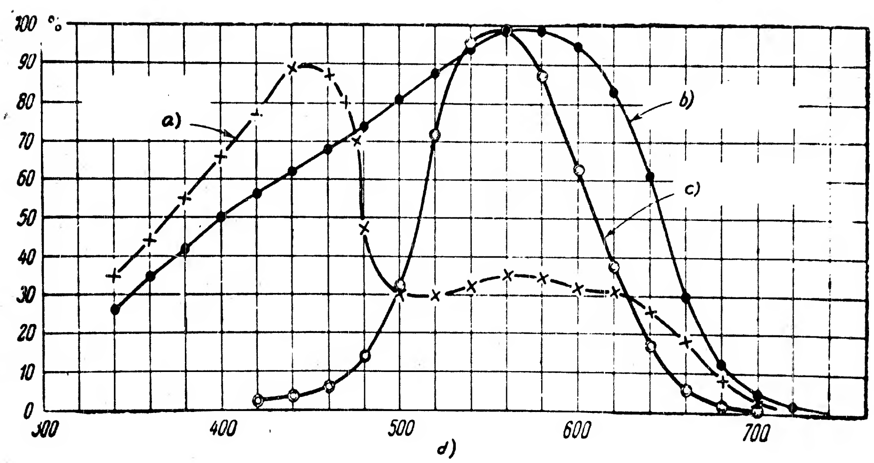

Fig.35. Relative Spectral Sensitivity of Selenium Photocell, Panchromatic Negative Material (Mean data) and Human Eye, (in %)

a) Panchromatic negative material; b) Selenium photocell; c) Human eye; d) Wavelength in millimicrons.

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substantially from the exact values of the exposure necessary under these or those taking conditions. The estimates made by the eye with the aid of visual methods, however, fluctuates so substantially with the spectral composition of the illumination that the possibility of obtaining any sort of stable and constantly high grade photographic results by their aid may be considered excluded.

It must be noted that the human eye, in spite of all its inherent shortcomings, still remains the only criterion for evaluating the naturalness of the photographic reproduction of tones. For this reason one of the principal demands that negative material for black and white photography must meet is the increase of its color sensitivity by every possible means and the improvement of its color reproduction by bringing the curve of spectral sensitivity of the emulsion as close as possible to the curve of sensitivity of the human eye. The smaller the differences between the color sensitivity of the negative materials and that of the eye, the smaller will be the possible errors in determining the exposure by means of a photoelectric exposure meter.

Thus the conclusion may be drawn: the closer the color sensitivity of the negative material to the spectral sensitivity of the eye, the better the results that a photoelectric exposure meter will yield in working on that material.

When negative materials of lower color sensitivity are used, the exposure values must ultimately be corrected accordingly. This is particularly necessary for photographs on orthochromatic plates, since the errors in determining the value of the exposure by means of a photoelectric instrument are inadmissibly high when they are used, owing to the differences of their spectral sensitivity.

When ordinary panchromatic negative film is used, these deviations are considerably smaller, and under the conditions of natural illumination they increase only in taking objects illuminated by the light of the blue sky (without direct sunlight).

For this reason, for the accurate determination of the exposure it is necessary

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to allow for the variation in the sensitivity of the films or plates used as a result of the fluctuations in the spectral composition of the illumination. Under the illumination conditions of interest to us, the sensitivity of the negative materials used must be found by means of test exposures, and these data used as the basis of an exposure calculation by the aid of the calculator.

The Soviet motion picture film industry has achieved considerable successes in producing high-sensitivity panchromatic negative emulsions which in their spectral sensitivity are rather close to that of the human eye.

Thus, even today, the considerable improvement of the color sensitivity of black and white negative materials and the widespread development of color photography already serve as the practical justification of the widespread use of photoelectric exposure meters.

Temperature Influences

Variations in temperature have a certain influence on the operation of photocells, and therefore on the accuracy of the readings of an exposure meter. The effect of temperature fluctuation on the accuracy of the exposure measurements has a practical effect only with very great fluctuations of the temperature connected with changes in time and place of the picture.

Studies have shown the existence of a large negative temperature coefficient. This means that with increasing temperature the value of the photocurrent rapidly declines. Under ordinary temperature conditions this decline of the photocurrent generated by the photocell reaches 0.2-0.3% for each degree of temperature increase. When the temperature is further increased to 40-50°C, the decrease in the photocurrent is appreciably accelerated. When the temperature decreases, the photocurrent increases.

Research has shown that the photocurrent reaches its maximum when the temperature is reduced to 2-6°C. On further lowering of the temperature, the increment of photocurrents markedly decreases. Within the limits of small temperature fluctu-

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ations the practical effect of this factor on the results of exposure measurements may be neglected. With a considerable increase of temperature, however, as occurs, for example, in the Central Asian republics, the influence of the temperature factor increases so considerably that it is necessary to apply a correction factor in determining the exposure.

The prolonged storage of a photoelectric exposure meter at temperatures of the order of $50^\circ C$ appreciably lowers the sensitivity of the instrument. An exposure meter should therefore not be exposed to prolonged overheating.

Constancy of Exposure Meter Readings

In evaluating the constancy of photoelectric exposure meters, we must distinguish and consider separately the inconstancy of their operation due to the phenomena of short-period fatigue, and the variations of their sensitivity over an extended period of time. If the photocell of an instrument is subjected to the action of illumination of the order of 100,000 lux (roughly equal to the illumination produced by the sun in the summer months), then, after only a few minutes from the beginning of the action of the light, a considerable fall in the photocurrent generated by it may be noted, reaching [illegible]% and more. In darkness, such a "fatigued" exposure meter recovers its sensitivity, and the current generated by it again attains its former value.

The inaccuracies introduced into the measurement results owing to the phenomena of fatigue depend primarily on the intensity of the illumination to which the sensitive surface of the photocell was exposed. Thus, if the photocell of the instrument has been exposed to brief illuminations of the order of 1000–5000 lux, which are usual in the practice of black and white and color takes in the motion picture studio, these inaccuracies do not exceed 2 to 6%, but at higher illuminations they reach a few tens of percent.

In measuring low illuminations, therefore, the constancy of operation of the photocell may be considered to meet the requirements of exposure measurements.

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At higher levels of illumination, prolonged illumination of the sensitive surface of the photocell must be avoided in every way. In case of the measurement of high brightnesses, the phenomenon of fatigue must likewise be taken into account. In checking the brightness of sources of illumination and the measurements made under conditions of very high illumination, neutral gray filters should therefore be placed in front of the photocell of the instrument.

To regulate the light flux falling on the sensitive surface of the photocell, some exposure meters are provided with a special iris diaphragm. For this reason, in type [illegible]-3 and [illegible]-4 exposure meters, in order to avoid the photocell getting out of order when, the pointer of the instrument deflects beyond the limits of the scale, the diaphragm must accordingly be closed.

The question of the constancy of the operation of the photocell over a prolonged period is of very great practical importance.

Tests have shown that the sensitivity of photocells kept in the dark and illuminated periodically by small illuminations of (100-2000 lux) varied by 4-5% after 6 months of testing. Photocells subjected to the action of daylight (illumination of the order of 10,000 lux) gave a fall of as much as 10% in the photocurrent, while photocells periodically illuminated by the sun had a fall of 15-20% in photocurrent.

For an exposure meter operating under varied, if not always, high illumination, the constancy of its action may be considered to be in practice satisfactory.

In spite of the high constancy of the operation of modern photoelectric exposure meters, their technical state and the accuracy of the measurement results obtained by their aid must be regularly checked under the conditions of motion picture production.

Checking the Operation of Exposure Meters

A periodic check of exposure meters, and above all, of instruments used to run parallel tapes on film, must assure the necessary uniformity of the results obtained

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with them. At the present time a technique of tests has been developed in the system of motion picture photography, and installations for checking all the principal parameters of exposure meter operation are installed at some studios of the USSR.

Frequently, even among new exposure meters that have not yet been used, considerable discrepancies in the readings are often observed, reaching 30% and even more. These discrepancies are connected with the nonuniformity of the characteristics of selenium photocells. Even new instruments which have not been tested and are not provided with technical test certificates, must therefore be subjected to comparative control tests.

Under the conditions of motion picture work and of the work of amateur photographers, the usual studio methods of testing the accuracy of the readings given by an exposure meter prove to be impossible to carry out.

In such cases, for short expeditions, satisfactory results are given by the method of testing the operation of an exposure meter based on the measurement of the relatively constant brightness of the northern part of the clear sky, in the interval between 11 and 13 hours in cloudless weather.

Before the departure of the expedition, simultaneously with the studio tests of the exposure meter under these conditions, the brightness of the northern area of the sky is measured, and the result of this measurement is used as the basis for estimating the results of the subsequent control measurements.

During the measurement the exposure meter is pointed towards the northern part of the sky at an angle of 45° to the horizon.

It must be borne in mind that the presence of even a slight haze may substantially affect the results of the measurement.

It is therefore desirable to make test measurements under conditions approaching those of the original control measurements.

Experience has shown that in cases when the control measurements of the brightness of the sky differ from the initial value by not more than 25%, the accuracy of

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the instrument readings may be considered to satisfy the requirements of practical photography in the open air.

An exposure meter may also be tested by comparing its readings with those of an instrument known to be in good condition and verified. If the sensitivity of the photoelectric exposure meter being tested has changed, then on the basis of the data of such comparison, a table of the corresponding corrections may be compiled.

TECHNIQUE OF DETERMINING THE TIME AND CONDITIONS OF EXPOSURE BY THE AID OF PHOTOELECTRIC INSTRUMENTS

The Use of Photoelectric Exposure Meters

One of the important circumstances making it necessary to abandon the visual determination of exposures is the transition to the processing of motion picture negatives on developing machines and the widespread use of the method of time development of photographic negatives, which requires great accuracy in determining the conditions of exposure of each individual take. From the point of view of the operator, as an artist, the advisability of adopting a mechanized and exactly controlled method of developing negatives is due to the urge to exclude the influence of random factors not dependent on the will of the operator himself and which distort the artistic and mimetic solution thought out by him.

The necessity of a transition from handicraft methods of laboratory processing to the processing of motion picture film on developing machines is likewise due to the purely technical demands that the negative must meet in connection with the union of image and sound-track on a single film.

Since the standard processing of the sound track is a necessary condition for the high quality of the sound, it follows that when image and sound are joined in a single positive, the negative and positive images cannot be developed to a random density determined by eye.

When the constant regime of processing motion-picture negatives and developing

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still photographic negatives by time is observed, significant deviations of the conditions of development from the established norms proved impossible and therefore the requirements for the accuracy of exposure of each individual negative must sharply increase. The existence, at the same time, of various types of actinometers, photometers, and similar instruments for determining exposure, owing to the fundamental shortcomings of their design, could not assure the necessary constancy of the results obtained by their aid.

In 1932 the first photoelectric exposuremeter brightness meter, designed to measure the integral brightness of the object photographed, appeared. The relatively satisfactory performance of such an exposure meter for takings under the conditions of natural illumination was explained by the large photographic width of the negative materials, by the relatively limited brightness interval of most photographic objects, and principally, by the low demands on the accuracy of exposure measurements that were made by photographic practice. For the purpose of determining exposure, and all the more for the control of the adjustment of illumination in the motion picture studio, the technique of measuring the integral brightness cannot be considered satisfactory.

The reservation must be made that, in individual cases, when the photographic objects are uniformly illuminated and have no considerable contrast, the use of the method of measuring the integral brightness may give satisfactory good results. However, in cases when the interval of brightness of the object and its contrast of illumination are great, attempt to determine the time and conditions of exposure by measuring the integral brightness lead to unsatisfactory results.

The methods of determining exposure based on measurements of the brightness of individual elements of the object to be taken are considerably more advanced. In motion picture work, in combination with the results obtained in control measurements of the textures, and study of standard developed exponometric wedges (exponograms), the use of this technique assures not only the accurate establishment of the

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optimum conditions of exposure, but also the possibility of a determination by preliminary calculation of the total densities of the individual parts of the negative.

Since, in work in the motion picture studio, the operator, by varying the position and power of the sources of light, has every opportunity to regulate the illumination of individual areas of the object, and as a result also the contrast of the object, the problem of determining the value of the exposure in studio work must be solved in a fundamentally different manner. In connection with this it is necessary to bear in mind the differences in the conditions of exposure for a photograph taken in the open air, under the conditions of natural illumination, when the illumination of the scene to be taken, and the brightness of the individual elements of the object are predetermined, and a studio shot.

Under ordinary conditions of photography in the motion picture studio, in determining the conditions of exposure the operator is interested not in the question of the size of the stop and the exposure time assigned by the conditions of the picture and by the effort to obtain maximum utilization of the speed of the lens used, but rather in the values of the brightness of differently illuminated elements in the subject in connection with the question of their correct photographic reproduction.

The computational determination of the necessary brightness and value of the exposure is a very laborious task, taking much time, and cannot be carried out under the conditions of a motion picture take. Other methods are therefore used in practical work.

The Method of Measuring the Variation of the Least Bright Element of the Object to be Taken

In working by this method the brightness of the darkest area of the object is measured. In accordance with the minimum brightness so determined, the necessary calculation of the exposure can be performed, or the time and conditions of exposure

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for a given negative material may be established by the aid of the calculator. When the measurements are accurate and the calculations are correct, the value of the exposure so determined will be equal to the minimum value of the exposure that is correct under the given conditions of illumination and with the given character of the object. Since the density of the shadows under these conditions of exposure will correspond to the densities of the lower part of the characteristic curve, determined with allowance for the value of the minimum useful gradient, it follows that the details in the shadows will show up well, and their brightness will be proportionally reproduced on the negatives. If the contrast of the object of the picture and the interval of illumination of the optical image are not great, and the value of the maximum correct exposure corresponding to the brightness of the brightest sections of the object does not go beyond the limits of the useful interval of exposures, then the details in the high-lights will also be correctly reproduced.

When these conditions are observed, the densities of the negative obtained as a result of exposure and development, and corresponding to the minimum and maximum bright elements of the object, will not go beyond the boundaries of the useful intervals of density of the sensitive material employed.

In establishing the illumination of the motion picture decoration, the use of this method assures the good reproduction of details in the shadows of the objects, and of the half tones and high lights for the overwhelming majority of objects photographed.

The upper limit of brightness allowable in such cases is reached comparatively rarely in practice, since for most subjects the value of the interval of brightness of the object and of the negative densities corresponding to it are less than the useful photographic width of modern negative materials, determined with allowance for the value of the minimum useful gradient in the upper and lower portions of the characteristic curve. An exception may be strongly flashing surfaces and sources of illumination in the frame, the densities of which, in the negative, go beyond

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the limits of the working densities.

The importance of the exact determination of the minimum correct exposure is very great. In addition to the obvious economic and productive significance of the use of the smallest possible number of illuminating devices during takes in the motion picture studio, and of the smallest possible number of the personnel serving those sources of light, the exact determination of the minimum correct exposure takes on great practical significance in certain other cases of photography as well. Thus, for example, in taking objects with a large number of small details, in connection with the considerable scattering of light in the emulsion layer, the operator and photographer often have occasion to limit, to the maximum extent, the quantity of illumination of the sensitive layer, and to work at relatively low densities of negative blackening.

In these cases the unconditional correspondence of the conditions of exposure and the time of exposure to the value of the minimum correct exposure is an indispensable condition for obtaining results of good quality.

If this requirement is not met, and the value of the minimum negative density is further lowered, beyond the limits of the densities corresponding to the minimum correct exposure, then the proportionality of contrast reproduction in the shadows of the object will be impaired.

The method of measuring the least bright element of the subject and of establishing the time and conditions of exposure by determining the value of the minimum brightness is the most rational from the point of view of economy of light, and completely assures the production of negatives with the necessary and sufficient densities.

In cases where the brightness of the brightest element of the subject is lower than the limiting brightness that can be correctly reproduced, the general density level of the negative may be raised by lengthening the exposure to the extent at which the brightness of the brightest area of the object, and the densities corre-

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sponding to it, will not go beyond the limits of the useful interval of densities.

The measurement of the brightness of the individual areas of the object to be taken must allow for the angular field of the instrument, in immediate proximity to the measured surface. For most modern exposure meters having an angular field of 45-60°, the measurement must be made at a distance not exceeding the width of the area of the surface being measured. In this case one should be sure that uniform and uniformly illuminated parts of the area to be measured are within the limits of the angular field.

Method of Measuring the Brightness of a Standard White Surface

In view of the impossibility of accurate measuring the brightness of small areas of the objects photographed, and likewise of the difficulty of measuring low brightnesses of areas with low coefficients of reflection, a frequently used method is that of measuring the brightness of a standard white surface, set up in place of the area of the object for which the exposure is being determined, or the level of illumination is being established, is often used. This method is successfully employed in cases when the brightness of a dark colored surface, or of a faintly illuminated surface, is very low and cannot be accurately measured. For determining its brightness by calculation with the aid of the exposure meter, under the conditions of a higher illumination, the brightness of a surface, analogous in coating and texture to the area of the surface, is measured. Then, under the same illumination conditions, the brightness of a sheet of white paper placed on the surface is measured.

The ratio of the brightness values obtained as a result of these measurements determines the ratio of the coefficient of reflection of the surfaces of the measured object and the white paper.

The paper is then placed on the dark and only faintly illuminated section of the object whose brightness could not be measured directly and its brightness is again measured. By dividing the brightness of the white paper so obtained by the

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ratio of the coefficients of reflection of the surfaces of the measured part of the object of photography and that of the paper, we obtain the required value of the brightness of the dark area with which we are concerned.

Knowing the approximate values of the coefficients of reflection of the standard white surfaces, and of the corresponding area of the surface of the objects photographed, and using the method of substitution, we may easily establish the value of their brightness.

This method may be supplemented by using a selection of textures and coatings of the decorations used in taking the film, the brightness of which must be measured under the same illumination conditions in which there is an area of the photographed objects that is analogous in its makeup. Under the same conditions the brightness of the white reference standard is also measured.

In this case the ratio of the brightness of one coating or textures or another, determined by the aid of the exposure meter, to the brightness of a matte white surface similarly illuminated (which, with a certain degree of approximation, is taken as unity) determines the coefficient of brightness of the texture under examination. A white baryta surface is used as the reference standard for these measurements.

The data on the brightness of the surfaces being taken, obtained by measurement, may be directly utilized in calculating the exposure by the well-known formulas.

These same data may also be used as the basis for determining the exposure conditions or for setting the required level of illumination for each of the textures used, by means of photographing the exponogram.

It must be noted that the method of measuring the brightness of a white reference standard is essentially a method of indirect measurement of the illumination of the given surface, since the brightness of a standard white surface of a reference standard that diffusely scatters light depends only on its illumination. In making these measurements, the exposure meter is set up at an angle to the white

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baryta surface of the reference standard, whose dimensions have been determined allowing for the angular field of the instrument and exclude the incidence of outside light rays on the sensitive surface of the photocell.

Method of Measuring the Brightest Element of the Object Taken

The attachment of the white reference standard to the exposure meter should assure its easy replacement by texture specimens.

In taking very dark subjects under low illumination, when the brightness of the details of the frame that are important for the subject is very low and cannot be measured by the exposure meter, where it is inconvenient, or, for some reason, impossible, to use the method of substituting a standard white surface, the method of measuring the brightest element of the subject may be employed.

The determination of the exposure is based on the measurement of the brightness of that lightest element of the object taken the correct reproduction of the brightness and details of which is essential. The maximum correct exposure so found will correspond to the densities of the upper segment of the characteristic curve. In this case the contrasts will be reproduced in correct proportion, together with all the darker areas of the objects, whose brightness is not less than 1/L of the value of the brightness of the brightest element of the subject, where L equals the useful photographic width of the negative materials used.

Since the photographic width of modern black-and-white films and plates reaches 1:256 or more, the minimum allowable brightness of the darkest areas of the photographed objects that will still be correctly reproduced by the layer may be taken as equal to 1/128 to 1/256 of the brightness of their brightest elements. For color pictures, in connection with the relatively small photographic width, and the small color range of multi-layer films, this ratio will be considerably smaller. The use of this method of determining the exposure completely assures the correct reproduction of the details in the high lights of the object. In cases of very great brightness interval of the object being photographed and the use of

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negative material with a small photographic width, the proportionality of the reproduction of the contrasts and details in the shadows may be impaired.

It is important to bear in mind that, when using this method, the sources of illumination in the frame, for example, lamps, chandeliers, etc, must not be measured as the brightest element.

From the point of view of economy of light, the method of measuring the brightest element of the subject is an irrational production method and leads to the production of negatives of elevated density.

The use of this method makes it possible to use exposure meters of lower sensitivity for the measurements.

In cases requiring a considerable degree of exactness, the value of the exposure may be determined by estimating the brightness of both the brightest and least bright elements of the object being photographed.

A disadvantage of this method is the necessity of making a relatively large number of measurements.

Measurement of the Brightness of the Main Element of the Objects of Importance with Reference to the Subject

In the practice of motion picture photography, all the above enumerated methods of determining the exposure, in order to establish the necessary light balance are usually supplemented by measuring the brightness of the main area of the frame having subject importance. The object of measurement in these cases is the brightness of the face of the principal personage of the scene being taken. In many cases, the peculiarities of the construction of the motion picture set, arising in connection with the montage solution of the film, force the operator to maintain a certain constancy of the density of the face of each given personage in all the frames of a subject-montage composition, maintaining the constant character of the illumination of the scene. This requirement cannot be extended to all cases of motion picture

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practice. Thus, for example, in special effects, the illumination in taking silhouette or semi-silhouette images, it is no longer expedient to maintain constant density of the face by comparison with the other scenes.

To assure constant negative density of the subject-important elements of the image in a motion picture take, it is necessary strictly to maintain and control the constant brightness and constant brightness ratios of the principal areas of the object taken.

In connection with this the accurate determination of the brightness of individual sufficiently small elements of the objects taken is the most important condition of the successful use of this method of determining exposure. However, when using exposure meters with relatively large angular fields, the attainment of the necessary accuracy in measuring the brightness of small areas of the object taken becomes very difficult. This is explained by the fact that the measurements made with it represent only the measurements of the integral brightness of sufficiently large surfaces. The measurements of the brightness of the faces of the principal personages, made by the operators from a distance of 20-25 cm, likewise represent only the measurements of integral brightness, and do not give exhaustive grounds for estimating the value of the individual details of the brightness which characterize the given object, for example the brightness of the brow, cheeks, etc.

The data obtained by such integral measurements could serve as a basis for the accurate determination of the exposure, for most objects, only where the contrasts of illumination are small. In cases of high contrasts of illumination, however, the accuracy of the measurement of the brightness of individual details in color shots in the moving picture studio is often inadequate. This is due to the fact that the results of the measurement of the brightness of one area of the object photographed or another are determined not only by the illumination, but also by the peculiarities of the reflection of light by them, and may be composed, in the most varied combinations, of diffuse and directional reflection.

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In cases of diffuse deflection, the brightness of a surface reflecting light, obeying Lambert's law, will be the same in all directions, and its measurements with an exposure meter-brightness meter involves no difficulty whatever. But where the directional reflection is either predominant or of considerable value, the readings of the exposure meter will fluctuate over a wide range even for the most insignificant variations of the position of the instrument (with respect to the measured area of the objects taken) which may lead to substantial errors. Measurements of brightness must be made at the same angle at which it is "seen" by the surface of the camera lens.

Direct measurements of the brightness of the object are often supplemented by measurements of the brightness of a standard white reference surface. Being essentially a method of indirect measurement of the illumination of the diffusely reflected light of a white surface, this method has proved to be not without substantial shortcoming.

Measurements of Illumination

A method of measuring the illumination of the principal elements of the object taken, of making control measurements of the illumination of secondary areas, and of the spatial illumination, has been worked out. These measurements are made by means of lux-lightmeters with scales calibrated in units of illumination, or also by means of exposure meters provided with special attachments (Fig.36). When the method of measuring the illumination is used in exposure measurement in practical exposure measurements, which is usually based on the determination of the brightness of the object, certain modifications must be made in exposure measurement practice, which is usually based on the determination of the objects brightness.

It must be borne in mind that for textures possessing a considerable directional reflection, and for a flashing surface, measurements of illumination cannot provide an adequate basis for estimating the brightness of these objects, and is therefore little applicable.

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In connection with this, the data on the illumination obtained as a result of measurements cannot serve as a direct basis for determining the value of the illumination produced on the sensitive layer by the optical images of the object taken.

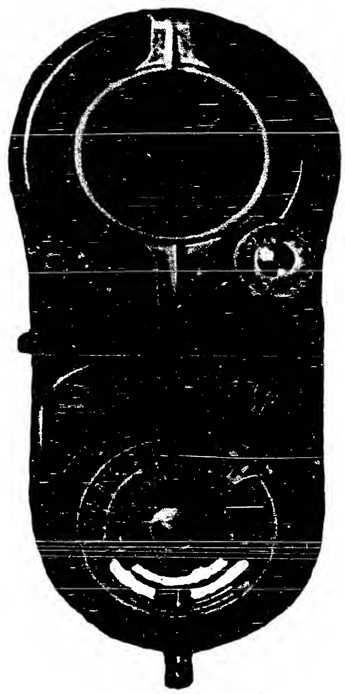

Fig.36. The EP-4 Exposure Meter with Attachment for Measuring Illumination
a) Low brightness; b) Illumination; c) Brightness

The use of a method of illumination measurement must therefore be preceded by a preliminary study of the textures and coatings used in the shop. The appropriate test exposures and shots of the exponometric wedges must be taken. A study of the data so obtained will make it possible exactly to fix the upper and lower limits of illumination of the scene being shot with respect to the assigned imitative effect, to the textures, and to the peculiarities of the negative materials being used.

The simplicity of the method of measurement and the high accuracy of the results, even at very low illumination, makes this method entirely justified under productive conditions.

The method of measuring illumination becomes particularly in constructing the illumination of the scene being taken. By determining, with the aid of test exposures, the necessary quantitative characteristics of the illumination of the principal textures and coverings used, the operator is enabled to establish the necessary and sufficient illumination level of the main and secondary elements of

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the objects.

The use of an exposure meter for measuring illumination very greatly facilitates the operator's work in establishing the illumination in taking panoramas, or the passage of the actors and objects moving along the most complicated paths. By means of such measurement it is possible to establish the necessary illumination over the entire path of the object and to establish in advance the entire illumination setup, which helps substantially to speed up the shooting process.

In usual cases of measuring the illumination, an exposure meter provided with a special attachment is set up in the immediate proximity of the corresponding area of the object taken and is pointed towards the principal sources of illumination.

In connection with the very great angular field of the caps used for measuring the illumination, the exposure meter automatically allows for the influence exerted on the total level of illumination of the objects taken by all other secondary sources of light located in the foreground hemisphere (the light of the sky, the light reflected by the clouds, the light of additional lighting installations, etc).

The value of the maximum illumination of the measuring elements of the scene, so determined, are used as the basis for the determination of the time and conditions of exposure.

In shots under the conditions of natural illumination on an open place, the illuminations on the object taken and in the camera coincide. For this reason measurements of illumination in open-air shots may frequently be made directly beside the camera.

In the reproduction of the special effects connected with the high contrasts of the illumination of the scene taken, it is in many cases necessary to determine exactly not only the maximum illumination but also the minimum illumination that can still bring out the details in the shadows of the object as required.

In such cases the measurements of the illumination of the scene make it possible rapidly and accurately to control the contrasts of illumination and to fix the

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necessary constancy of the character of the illumination of all frames of the episode being filmed. For this reason, in motion-picture studio work, besides the level of illumination of the main objects, it is also necessary carefully to control the illumination of the background elements. In cases where the figures of the actors move in the space of decorations, it is necessary to measure the level of spatial illumination as well.

Use of Exposure Meters in Color Shots

Since even insignificant deviations in the exposure of color films substantially affect the quality of the color reproduction, it is an indispensible condition for obtaining good results with color shots that all exposure measurements and calculation shall be accurately and carefully made. The limit of error of exposure for most subjects of color shots is very low.

In connection with this, the exposure time must be determined with an accuracy within 50%, and the value of the effective aperture within $\frac{1}{2}$ division of the normal stop scale.

One of the most important conditions of correct color reproduction is the most complete utilization possible of the region of normal exposures for all three layer of the color film. For this it is necessary precisely to establish the minimum and maximum brightness of the objects whose color must be correctly reproduced on the photograph or on the screen.

At excessive intervals of brightness, exceeding the width and the color range of the film, and also with incorrect determination of the minimum and maximum brightness of the object, distortions of the color reproduction, adversely affecting the quality of the picture, result from local underexposures and overexposures. This can be avoided only by the most careful control of the contrast of illumination and brightness of all elements of the object by means of an exposure meter.

This work must precede the establishment by means of test exposures of the exact values of the minimum and maximum brightness for the principal color textures

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used in the shop. This is particularly important in connection with the fact that in working on multi-layer negative materials, the conditions of illumination and exposure must be determined with full allowance for the color tonality and texture of the objects being taken and for all the peculiarities of their reproduction on color film.

The practical importance of the exact establishment of these values for the correct reproduction of the color tone of the human face in the picture is exceptionally great.

In determining the time and conditions of exposure by the exposure meter calculator the practical establishment of the accurate value of the sensitivity of the negative material utilized in a color film shot becomes particularly important. This is particularly important because color films on storage lose rather rapidly a considerable part of its color sensitivity. Their sensitivity is often halved already during the first year of storage, and in many cases the actual sensitivity of color films which the amateur motion picture or still photographer meets in his practice, does not exceed 50-60% of the original sensitivity.

It must also be borne in mind that this reduction of sensitivity is often connected with impairment of the balance between the layers of the color film with respect to both sensitivity and to contrast.

In connection with the differences between spectral sensitivity of the photocell and that of the film, and also with the differences in the spectral characteristics of the objects taken, the exact determination of the necessary exposure time by means of the calculator is difficult in certain cases of color photography. It is therefore necessary to apply certain corrections to assure the quality of the color reproduction in amateur photography under the conditions of exposure determined by measurement of the integral brightness. The exact value of these corrections can be established by means of test exposures.

In taking bright subjects illuminated by the sun with brightly colored details,

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the index of sensitivity of the film in GOST units must be set up on the calculator of the instrument in accordance with the actual sensitivity of the color film being used.

But in cases with a predominance of darker objects, the index of sensitivity must be reduced and taken as equal to about half its original value to assure the quality of their color reproduction.

To facilitate the correct reproduction of dark or very dark painted objects, the index of sensitivity of the film must sometimes be reduced even more.

In shots in overcast weather, for calculating the conditions of exposure by the aid of the calculator, the index of sensitivity of the color film used must be reduced by 30-40%. This relates to cases of bright objects. In taking dark painted objects, this reduction of the index of sensitivity may reach the 50% level.

Determination of the Practical Color Sensitivity of Negative Materials

The correctness of the calculations performed by the aid of the calculator depends to a very great extent on the accuracy of the determination of the sensitivity of the negative material used. Nevertheless not only the amateur photographer, but even some specialists who pay much attention to making exposure measurements, sometimes fail to verify in practice the accuracy of the data on the sensitivity of negative materials.

The principal advantage of the GOST method of general sensitometric tests, by comparison with the methods previously employed, is the approach of the conditions under which the photographic materials are tested to the conditions of their practical use. In spite of this fact, the data on the sensitivity level given on the packing of the plates and films do not always exactly characterize the value of their practical sensitivity under the specific conditions of use. The utilization of these data without allowing for the partial loss of sensitivity as a result of storage, and also the influence of development and certain other factors, cannot assure the necessary quality of the results.

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In connection with this, the high accuracy of the data on brightness or illumination of the objects taken, obtained as a result of exposure meter measurements, is combined in the calculations with values that are merely approximate and very inaccurately characterize the sensitivity of the plates and films used.

For this reason, it is expedient in practical work, by means of test exposures with the aid of an exposure meter, to establish the exact value of the sensitivity of the negative materials used. For the successful conduct of these test exposures it is necessary:

1) To measure the brightness of the objects being taken, or its illumination, and, taking as the starting point the nominal sensitivity of the material, to determine by the aid of the calculator the necessary exposure time and lens stop. The photographed object must be uniformly illuminated, and differences in the brightness of individual elements of the object must not be too great.

2) To make the first test exposure in accordance with the results of the calculation of the exposure and stop on the calculator.

3) To make two test exposures, increasing the illumination of each of them by [illegible] in comparison to the last one, i.e. by half a division of the diaphragm scale. The illumination on the sensitive layer may be increased also by using the photo shutter, by lengthening the exposure.

4) To make two test exposures reducing the illumination of each of them by comparison with the preceding one, likewise by half a diaphragm-scale division.

5) To develop all the material taken in the developer usually used at normal temperature, and with the exact normal development time for the given developer.

6) To select, from a number of negatives of different density, the best one, which to the greatest extent corresponds to the requirements of correct reproduction on the picture or screen, of the contrasts of the objects, and all the subject important details. To establish the conditions of the exposure of this negative (the stop and exposure time) by determining how many times the illumination received

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on it by exposure is greater or less than the initial value of the exposure.

The greatest differences in the exposure conditions of these five negatives will have a ratio of 4 to 1, and will cover an interval of exposures which in most cases will assure the exact establishment of the value of the actual sensitivity of the film as well as the testing of the exposure meter.

Taking into consideration the fact that the quantities expressing the sensitivity in GOST units are directly proportional to the relative practical sensitivity of the negative material, it is necessary to divide or multiply the original value of the sensitivity, expressed in GOST units, by the correction found as a result of the test exposure.

The result of the calculations will determine the practical value of the sensitivity of the negative material with respect to the given conditions of taking and laboratory processing, and likewise to the peculiarities of the exposure meter.

A technique of which does not differ in principle from the above described is widely used in motion picture practice as well. It reduces essentially to obtaining, by means of a motion picture camera, a series of regularly decreasing or increasing exposures. Under the conditions of standard laboratory processing of the material so shot, the resulting densities and photographic characteristics of the negative image so obtained may be used as a basis for estimating the sensitivity and other properties of the film.

[illegible],

[illegible]

As early as 193[illegible], at the laboratory of photographic technique of the All Union Research Institute for motion picture photography ([illegible]) the first experimental prototypes of Soviet photoelectric exposure meters were built. Together with portable instruments a large exposure meter of studio type was also put out, designed for photometry of complex combined frames.

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In the following years, alongside of various experimental models, the type EP-3 of the NIKFI-MKIP exposure meter, and the EP-4 exposure meter, which is now being produced by the Soviet motion picture machine industry, were developed.

The EP-4 Exposure Meter

The exposure meter of this type is a universal instrument for measuring the brightness, together with the illumination, of the object being taken. It consists of two principal parts, connected by a vertical spindle. The upper movable part of the instrument, in which the photocell is located, is rotated with respect to the lower part, which contains a high-sensitivity DC electrical measuring device and an exposure calculator. The scale of the micrometer is calibrated in relative units from 1 to 10. The values of the absolute brightness for illumination corresponding to one scale division are entered in the test certificate of each exposure meter and correspond on the average to [illegible] apostilbs, for measuring great brightness values; to [illegible] apostilbs for measuring small brightness values; and to [illegible] lux in measuring illumination.

The photocell of the instrument, with an active sensitive surface of $10\ cm^2$, is placed in a special conical compartment. In front of the entrance aperture of this compartment, an iris diaphragm is installed to regulate the light flux falling on the surface of the photocell. The openings of the compartment and the diaphragm are protected from dust and moisture by a cover glass. The exposure meter is provided with two interchangeable caps, rotating about a vertical axis: one for measuring illumination, and the other for measuring medium and high brightness values.

The cap for measuring the brightness values, being a limiter of the angular field of the instrument, consist of a lens raster and a honeycomb lattice, mounted in a single mounting (cf. Fig.34). When using this attachment, the angular field of the instrument equals 45°. The cap for measuring illumination is provided with a ground glass. Low brightness values of the order of 40 apostilbs are measured with a fully opened diaphragm, without a cap. The angular field of the instrument

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is bounded in this case by the entrance aperture of the compartment and amounts to about 100°.

The cap used at the time of measurement is set in front of the entrance aperture of the photocell compartment. In measuring low brightness values, both caps are placed at the sides of the exposure meter, by opening the aperture of the compartment (Fig.37). The mountings of both caps are held in the base positions by means of locking device, which is released by a special lever placed on the side of the instrument.

The electrical measuring system is provided with a mechanism for checking the pointer, thus fixing the position of the pointer at the instant of measurement. This device considerably facilitates work with the exposure meter and extends the possibility of its industrial use. The mechanism of braking the pointer consists of a movable arc moving on a fine spiral spring attached to the end of the pointer. When a button at the side of the lower part of the exposure meter is pressed, the arc moves away and releases the pointer.

To widen the range of measurements, the [illegible]-4 exposure meter uses an iris diaphragm, by which the range of the instrument can be increased by factors of 2, 10, 20, 50 or 200, and can be fixed on each of these positions. In determining the value of the brightness or illumination, the readings of the instrument must be multiplied by the factor corresponding to the diaphragm opening. The range of measurement of the [illegible]-4 exposure meter is very great and covers all values of the brightness or illumination that are met in the practice of still or motion picture photography.

The calculator of the exposure meter has two movable discs and one fixed disc, on which the values of the relative lens apertures are entered within the range of 1:1.0 to 1:45, and also three pointers corresponding to the respective cases of exposures with measurement of illumination and measurements of small and great brightness (Fig.38).

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On the middle movable disc of the calculator, the exposures from 1/3000 sec to 2 min are entered. The indicator on this disc is matched with one of the divisions of the scale of sensitivity characterizing the photosensitivity of the

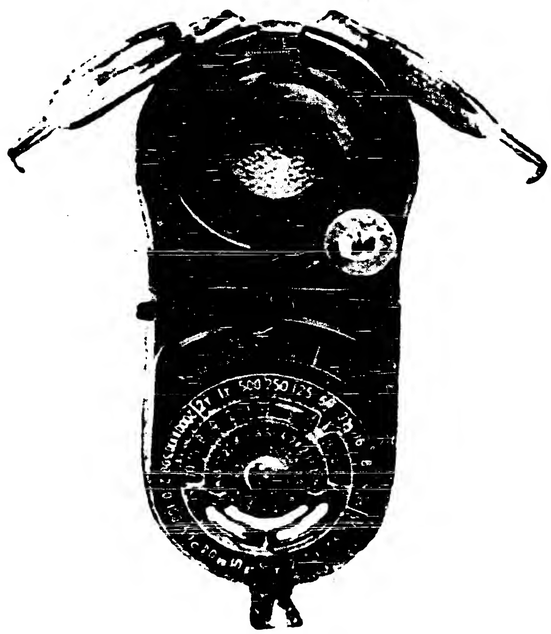

Fig.37. The EP-4 Exposure Meter. In Measuring Small Brightness Values, the Caps for Measuring Brightness and Illumination are Placed at the Sides of the Instrument by Opening the Openings of the Photocell Compartment

a) Low brightness; b) Illumination; c) Brightness; d) GOST

negative materials used in GOST units. On the lower disc of the calculator there is likewise a scale of light values ranging from 0.25 to 2000 arbitrary units.

The calculation of the time and conditions of exposure made by the aid of the

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calculator of the EP-4 exposure meter assures a density of the human face equal to 0.9 on the negative image when using a negative material of the given sensitivity, when this is developed to γ = 0.7. This calculation is based on the results of the measurement of the illumination of the object taken. The coefficient of reflection of the face here is taken as 0.3. The scale of relative apertures of the calculator

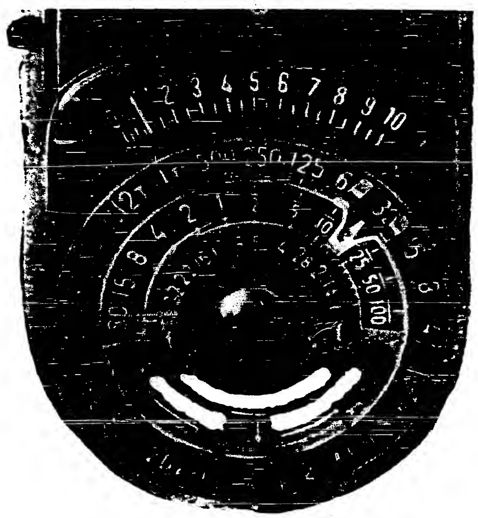

Fig.38. The Calculator of the EP-4 Exposure Meter

a) Low brightness; b) Illumination; c) Brightness; d) GOST

is figured for the use of coated lenses with a coefficient of transmission equal to 0.8.

For the proper determination of the exposure time and lens stop by the aid of the calculator, one must:

1) Measure the brightness or illumination of the object taken and multiply the value so obtained by the factor corresponding to the position of the diaphragm.

2) Match the pointer of the middle disc with the corresponding division of

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the scale of sensitivities of the negative materials used, expressed in GOST units.

3) In case of the measurement of the brightness of the object taken, place the pointer to "brightness" or "low brightness" and in measurements of the illumination the indicator "illumination" on the upper disc with the corresponding division of the scale of light values.

4) Read off, on the scale of exposures of the middle disc, the exposure time, expressed in seconds or fractions of a second, which is opposite the corresponding division of the scale of relative apertures on the upper fixed disc of the calculator.

As already stated, in determining the time or conditions of exposure, it is necessary to take into account the differences in the sensitivity of the negative materials used when utilized under the conditions of natural illumination or when incandescent bulbs are used. In this case, in shots on panchromatic emulsions, the value of the sensitivity on the calculator of the exposure meter must be set at 30-40% less than the nominal value fixed for shots under natural out of doors illumination or for lights with high-intensity arcs.

The Leningrad Exposure Meter

The type Yu-11 Leningrad photoelectric exposure meter makes it possible to determine the value of the necessary exposure not only from the brightness, but also from the illumination of the objects taken. On the side wall of the exposure meter is a rectangular opening of the photocell compartment. The angular field of the instrument is 60°. To limit the light flux falling on the sensitive surface of the photocell, a shutter with two openings may be placed in the compartment of the instrument. The use of this shutter, which covers a part of the photocell surface, reduces the amount of light falling on it by a factor of 40, and considerably widen the range of measurements.

Fig.39 gives a general view of this exposure meter. On the lower toothed disc of the calculator, in red and black, two scales of lens stops are placed, one of

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which is covered by a fixed sector. When the disc is turned, the scales exchange places and simultaneously automatically open or close the shutter. In cases of low brightness of the object taken and of low illumination, the exposure time is calculated on the red scale of lens stops and, using the red pointer. When the brightness or illumination of the objects taken is considerable, the black scale

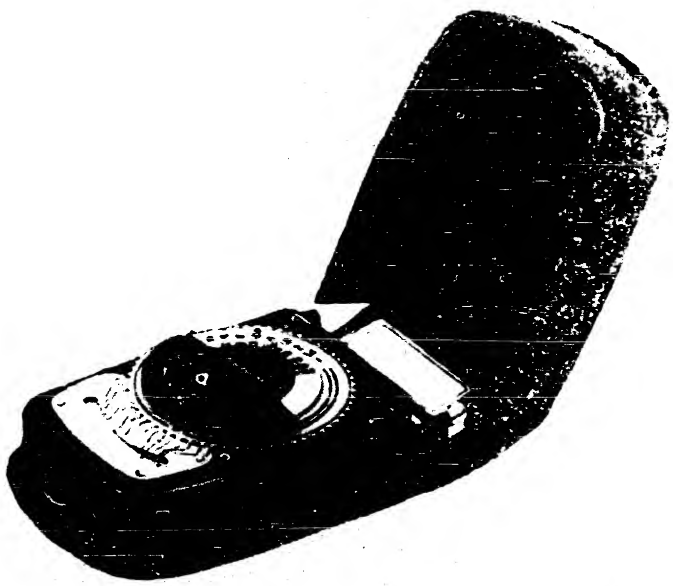

Fig.39. The Leningrad Type Yu-11 Exposure Meter in its Case

and the corresponding black pointer is used instead. On the upper disc of the calculator are placed the exposure times from 1/1000 to 60 sec and a scale of the photosensitivity values of the negative materials used, expressed in GOST units. On this same disc there is also a special index pointer corresponding to the exposure time for motion picture photography at a rate of 16 frames per second and an

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angle of obturator opening of 170-180°.

The micrometer scale is calibrated in relative units from 1 to 8. The approximate values of the brightness, or illumination, corresponding to the divisions of this scale, are given in Table 10.

Table 10

Approximate Values of the Brightness or Illumination Corresponding to the Scale Division of the "Leningrad" Exposure Meter

Divisions of micrometer scale	Brightness of measured area, (in apostilbs)		Illumination of object taken, (in lux)	
	With open shutter	With closed shutter	With open shutter	With closed shutter
1	10	400	50	2,000
2	20	800	100	4,000
3	40	1,600	200	8,000
4	80	3,200	400	16,000
5	160	6,400	800	32,000
6	320	13,000	1,600	65,000
7	640	25,000	3,200	130,000
8	1,300	50,000	6,400	250,000

When this exposure meter is used as a brightness meter for determining the necessary exposure time one must:

1) Match with the index pointer the division of the scale corresponding to the value of the photosensitivity of the negative material used.

2) Point the instrument at the object to be taken and rotate the disc of the calculator until the black index of the lower disc is matched with the division of the micrometer scale corresponding to the deflection of the pointer. If with closed shutter the deflection of the micrometer pointer does not exceed two scale divi-

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sions, the calculator disc must be turned until the red index pointer is matched with the corresponding division of the scale. In cases of high brightness of the object taken, however, when the micrometer pointer goes beyond the limits of this scale, the calculator disc must be turned in such a way that the black index is brought within the limits of the scale, and the shutter is closed.

3) Against the corresponding position of the scale of relative apertures, read off the required exposure time expressed in seconds and fractions of a second (Fig.40).

By the aid of this instrument, the exposure time may also be determined from the illumination of the objects taken. For measuring the illumination, a special cap with milk glass is used, which fits easily into the opening of the photocell compartment. The exposure time is calculated in the same way as in the case when the brightness of the photograph objects is measured.

It must be noted that in photographing certain very bright objects without a foreground (for example marine or distant winter landscapes), the exposure time determined by the aid of this exposure meter may be expediently halved. In shots, however, made against the light or in taking objects with a very dark foreground, the exposure time should be increased by a factor of 1.5-2.

In using this exposure meter it is expedient systematically to verify the zero positions of the micrometer needle.

It is obvious that to make this check it is necessary completely to exclude the admission of light to the sensitive surface of the photocell. In this case the pointer should coincide with the zero mark of the scale. If it does not do so, it should be matched with the zero division of the scale by means of the regulating screw in the body of the instrument.

The Exposure Meter of the "Kiev III" Camera

The minature cameras Kiev III produced by Soviet industry are equipped with a photoelectric exposure meter mounted in the upper part of the camera. Figs.41 and

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42 show a general view and a diagram of this exposure meter. The knurled ring to the left of the exposure meter is directly connected with the slide contact of a small rheostat inside the instrument. When this ring is rotated, a larger or smaller additional resistance is introduced in the circuit of the current generated by the photocell. The needle of the micrometer, which is deflected under the influence

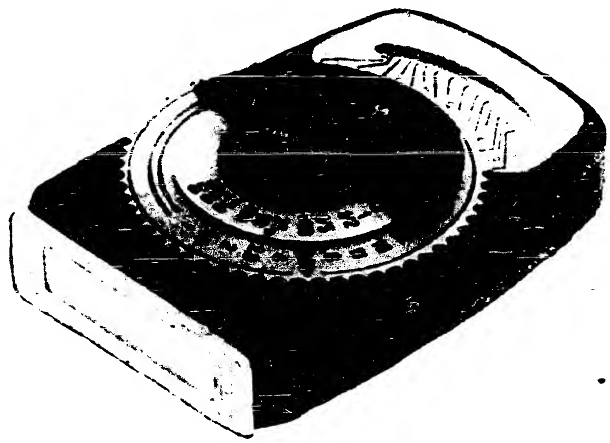

Fig.40. Type Yu-11 Leningrad Exposure Meter with Cap for Illumination Measurements

of the light acting on the photocell, reflected from the object to be taken, is again returned to its original position and is matched with the lozenge shaped sign on the scale. If the photocell of the exposure meter is subjected to the action of a higher brightness and thereby the photocurrent is increased, it is necessary to introduce more resistance into the circuit in order to return the needle to its original position. On the other hand, at a smaller current strength, the additional resistance must be very small.

Thus the value of the resistance included in the circuit may serve as a measure of the brightness of the object being measured. On the outside surface of the

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calculator of the exposure meter and of the knurled ring connected with the sliding contact of the rheostat, are placed: the scale of exposure times, the scale of relative apertures and a scale of sensitivity of the negative materials used. As a result of the measurement in accordance with the position of the knurled ring, at which the needle of the micrometer is matched with the lozenge-shaped sign of the scale, the value of the exposure required may be read off against the corresponding division of the scale of relative apertures.

At very low brightnesses of the objects taken, the current strength produced in the photocell circuit is so small that even at maximum lowering of the resistance, it is impossible to return the instrument pointer to its original position. The exposure-meter scale is therefore provided with additional divisions placed alongside the main indicator, a lozenge. This scale bears the figures 2, 5, 10, 20, 40. When the brightness of the objects taken is very low, the micrometer pointer, even with the resistance completely off, remains at or near one of these figures. In this case the necessary exposure time is determined by multiplying the value determined at the given position of the knurled ring by the number indicated by the instrument pointer. This device renders the range of measurements that can be made with this exposure meter very great.

The exposure meter of the Kiev III camera is a brightness meter with an angular field corresponding to the image angle of a lens of focal length 5.0 cm, and designed to make integral brightness measurements of the objects taken.

Differences between the angular field of the exposure meter and the image angles of lenses of different focal lengths may exert a very substantial influence on the results of measurements when interchangeable lenses are used.

In making integral measurements, the exact determination of the exposure conditions from the concrete values of the brightness of the principal elements is replaced by establishing only a certain "average" brightness of the object as a whole.

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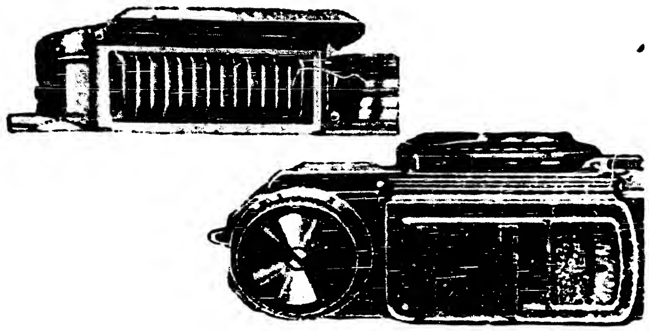

Fig.41. General View of Photoelectric Exposure-Meter of "Kiev III" Camera

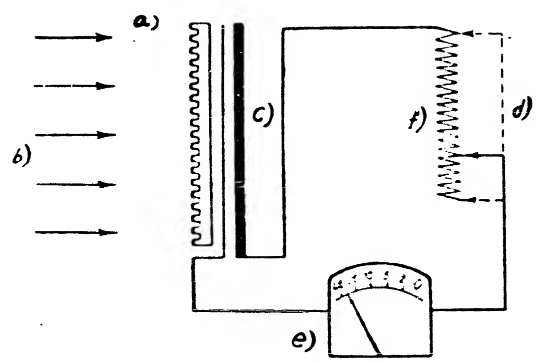

Fig.42. Scheme of Exposure-Meter of "Kiev III" Camera

a) Angular-field limiter; b) Light; c) Photocell; d) Contact slide; e) Micrometer; f) Rheostat

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In shots of objects with average brightness ranges including most of the subjects taken, the use of this exposure meter assures results of good quality. In shots of very high-contrast subjects, with great brightness ranges, this circumstance may lead to substantial errors in the determination of the exposure.

Certain corrections must therefore be applied to the readings of the exposure meter of the Kiev III camera for shots taken against the light, or of interiors, and when artificial light is used. Thus, for example, in a shot against the light, to assure bringing out the details in the shadows of the object, a somewhat longer exposure should be given than that indicated by the instrument. In interior takes, with natural illumination, it is expedient to reduce the exposure time somewhat.

When the object taken is illuminated with incandescent bulbs, owing to the difference between the different spectral sensitivity of the photocell and that of the negative materials used, it is expedient to increase the exposure time:

1) When using panchromatic negative materials of "Pankhrom-3" type, and panchromatic negative film of type B or V, by 50%.

2) When using ordinary panchromatic materials, by 100%.

3) When using orthochromatic negative materials, by a factor of about 2.5 to 3.

The exact value of these corrections should be found by test exposures. The sensitivity of the negative materials used, as already stated, is very intimately related to the conditions of development. The use of special, so-called fine grain developers in miniature camera work requires a certain increase in the exposure time of the film. Since precisely such developers must be used on the films taken with the Kiev III camera, this was already taken into account in calibrating the scale of the exposure meter of this camera.

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